THE USE OF SIMULATION AND CAN-Q TO ANALYZE THE CLEANING AND LUBRICATING PROCESSES OF COLD DRAWN TUBING

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PREFACE

A simulation in SLAM and an analytical computer program called CAN-Q were used to study the feasibility of adding cranes to the cleaning and lubing tanks at Southwest Tube Manufacturing.

A comparison is made of the trade-offs and difficulties in using SLAM and CAN-Q in the study. This is accomplished by comparing outputs of both programs, determining confidence intervals and comparing this data with the actual system. A cost analysis is also done on the feasibility of adding the cranes to the tanks.

I wish to thank my major adviser, Dr. C. P. Koelling, for his guidance.

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CHAPTER I

INTRODUCTION

One of the major problems in production planning today is bottlenecks or blockages of material flow through production operations. Southwest Tube in Sand Springs, Oklahoma has such a problem currently in their tank operation.

Southwest Tube produces hydraulic and mechanical tubing to specifications for customers. These tubes are cold-drawn and then heat treated through a furnace to a desired hardness. Before the tubes are cold-drawn, they must be chemically cleaned and lubricated. This operation is done in the tank system. Overhead cranes dip tubes in various tanks and then set them on a dryer after treatment. The tubes are then taken away to the cold-drawing production area. Currently the tanks cannot keep up with the production on the cold-drawing floor. This causes the floor to go idle waiting for more tubes.

One method to increase production is to increase the length of the work shift or add another shift. However, the tanks run 24 hours a day, seven days a week, so this plan has already been implemented. Another approach to the problem is the addition of cranes. This particular approach is the only feasible way that output can be increased through the tanks.

An analysis must be made of the addition of cranes to the system to find if the new equipment will really increase production, and to decide if the addition of cranes will be economically feasible.

One approach that lends itself well to this type of problem is simulation, however, simulation can be a very expensive and time consuming technique. Another approach that may apply well to this type of problem is an analytical technique called CAN-Q. This method is less costly than simulation. The proposed research deals with the application of simulation and CAN-Q to this type of environment, particularly Southwest Tube's production problem, and the cost effectiveness of adding the cranes.

CHAPTER II

LITERATURE REVIEW

Simulation

Simulation has been defined by Shannon (18) as

> the process of designing a computerized model of a system (or process) and conducting experiments with this model for the purpose of understanding the behavior of the system or of evaluating various strategies for the operation of the system (p. 24).

This particular definition of simulation seems to cover the more important aspects for the model building type of problem solving process. Of particular importance is the linking of simulation to the traditional model building approach to problem solving. This model building method, more commonly referred to as the scientific method, contains the following stages:

1. Observation of the system;
2. Formulation of hypotheses or theories that account for the observed behavior;
3. Prediction of the future behavior of the system based on the assumption that the hypotheses are correct; and
4. Comparison of the predicted behavior with the actual behavior.

However, since the scientific method requires previous observations, which is impossible for certain systems (especially those that do not exist), a slightly different approach to simulation is taken. This approach is called system methodology and consists of four phases: planning, modeling, validation and application.

Planning

The first phase in systems modeling is planning. It is at this phase that the modeler first encounters the system. The planner first determines a problem definition. Once the problem has been clearly defined, the modeler can collect pertinent data that might help in the problem solving process. The second stage in the planning process is to analyze the system to gain a thorough understanding of the system and the problem. Many simulation models fail because of an incomplete understanding of the system or the problem.

Modeling

The second phase in systems methodology is modeling. In this phase the analyst constructs a model from the system. The modeling of a system is made easier if: 1) physical laws are available that pertain to the system; 2) a pictorial or graphical representation can be made of the system; and 3) the variability of system inputs, elements, and outputs is manageable [Graybeal and Pooch (5)]. An analyst will try to simplify the system by using boundaries to limit the scope of the simulation within reasonable terms, limit the inputs and outputs to a level that will both be economical and maintain model integrity. The modeler will also draw a schematic or flow chart of the model so a better understanding of the model can be obtained. If the system is so complex that no representative model can be used, then a method of subsystem modeling is used. In this approach, the system is divided into smaller, less complex subsystems and an overall model is used to link the subsystems together.

Three approaches have been used in identifying subsystems [Graybeal and Pooch (5)]. The first type is the flow approach. This type of approach has been used to analyze systems that have a flow of physical or information items through the system. Subsystems are identified by grouping aspects of the system that produce a particular physical or information change in the flow entity. A second approach used to identify subsystems is the functional approach. This type of approach is used when no observable flowing entities can be found in a system. Instead, a logical sequence of functions being performed is identified and grouped into a particular subsystem containing all system characteristics that perform a certain function. The last method is called the state-change approach. This procedure is used in systems which are characterized by a large number of interdependent relationships and which must be examined at regular intervals to detect state changes. System characteristics that respond to the same stimulus or set of stimuli are then grouped to form a subsystem.

Once the subsystems have been identified they must be modeled. One task in modeling is choosing an appropriate simulation language. This depends on the type of modeling involved, the facilities available, and the analyst's knowledge of certain languages. After the language is chosen, a computer model of the system can be made.

Another task in the modeling phase is the estimation of the system variables and parameters. At this point real world data are summarized into a manageable statistical description of the system's characteristics. This is done by collecting data over some period of time and then computing a frequency distribution for the desired variables.

Validation

The next phase of system methodology is validation. A model is validated by proving that it is a correct representation of the real system. Certain techniques have proven useful in the simulation process. One technique is to compare the results of the simulation with results historically produced by the real system operating under the same conditions. A second technique is to use the simulation to predict results. The predictions are then compared with the results produced by the real system at some future period in time.

Naylor and Finger (12) use a three-step approach to validation of a simulation model. The first step is to develop a model with high face validity. A model that is face valid seems reasonable to people who are knowledgeable about the system under study. This is accomplished through conversations with experts, observations of the system, general knowledge of the system, and intuition on how the system operates. In the second step the assumptions of the model are tested empirically. This includes adequacy of fit tests used to assess distributions used in the model. This step also uses sensitivity analysis to determine the level of detail in a simulation model. The final step determines how representative the simulation output data is. This is accomplished by comparing the output of the real system to the simulation model, using statistical tests such as the t-test.

Just as good experimental design can aid in the data collection of the modeling phase, so can validation aid in correctness of the simulation model. Most standard experimental designs require that observations be taken on the system variables that can be controlled. The simulation model must operate under identical conditions [Graybeal and Pooch (5)]. Only then can valid inferences be drawn about the relationship between the resulting output of the real system and the outputs of the simulation model.

Application

The final phase of systems analysis is application. After verification, the simulation can finally be employed at four levels as described by Pritsker (16): 1) as explanatory devices to define a system or problem; 2) as analysis vehicles to determine critical elements, components, and issues; 3) as design assessors to synthesize and evaluate proposed solutions; and 4) as predictors to forecast and aid in planning future developments.

Simulation as a tool to solve complex problems has been growing by leaps and bounds with the improvement and reduction in cost in using the digital computer. Problems in fields as diverse as socio-economics, politics, law-enforcement, biology and nuclear engineering have been successfully solved with the use of simulation [Shannon (19)]. If simulation is so good, however, why is any other type of modeling used? The answer is that in problems where simulation is used, and even in cases in which it does apply, there may be easier and less expensive ways of solving the problem. Solberg and Ravindran (21) state that simulation is one of the easiest tools of management science to use, but probably one of the hardest to apply properly and perhaps the most difficult with which to draw accurate conclusions.

Advantages and Disadvantages

Adkins and Pooch (1) list five advantages of simulation modeling:

1. It permits controlled experimentation. A simulation experiment can be run a number of times with varying

input parameters to test the behavior of the system under a variety of situations and conditions.

2. It permits time compression. Operation of the system over extended periods of time can be simulated in only minutes with ultrafast computers.
3. It permits sensitivity analysis by manipulation of input variables.
4. It does not disturb the real system. This is a great advantage, since most managers would be reluctant to try experimental strategies on an on-line system.
5. It is an effective training tool.

They also list four disadvantages to using the simulation approach to problem solving:

1. A simulation model may become expensive in terms of manpower and computer time.
2. Extensive development time may be encountered.
3. Hidden critical assumptions may cause the model to diverge from reality.
4. Model parameters may be difficult to initialize. These may require extensive time in collection, analysis, and interpretation.

Thus, even though simulation can be a useful tool, it also has its drawbacks. These should be noted in considering the simulation approach to any particular problem.

Classifications

Simulation models of systems can be classified as either discrete change or continuous change. Pritsker and Pegden (16) describe discrete simulation as when the dependent variables change discretely at specified points in simulated time. These points are referred to as event times. In continuous simulation the dependent variables of the model may change continuously over simulated time. This is accomplished through differential or difference equations. Both discrete models and continuous models can be combined in one model. In this type of "combined simulation" the dependent variables of a model may change discretely, continuously, or continuously with discrete jumps superimposed.

In discrete simulation, the goal is to reproduce the activities that entities in the model engage in, and thereby learn something about the behavior and performance of the system [Pritsker and Pedgen (16)]. According to Kiviat (8), a discrete simulation model can be formulated by what are known as the three alternative world views for discrete simulation modeling. These three views are referred to as the event, activity scanning, and process orientation.

In event orientation, a system is modeled by defining the changes that occur at event times. Events that can change the state of the system are determined and then a logical association is made with each event type.

In activity scanning orientation, activities in which entities in the system engage are described. Prescribed conditions then cause an activity to start or end. The events which start or end the activity are not scheduled by the modeler, but are initiated from the conditions specified for the activity.

The last world view of discrete simulation is process orientation. In this view, sequences of elements occur in defined patterns.

In a continuous simulation model, the state of the system is represented by dependent variables which change continuously over time [Pugh (17)]. Models of continuous systems are frequently written in terms of the derivatives of what is known as the "state" variables. The state variables are the dependent variables that continuously change over time.

Combined discrete/continuous model variables may change both discretely and continuously. The system can be described in terms of entities, their associated attributes, and state variables.

Pritsker and Pegden (16) state that there are two types of events that can occur in combined simulations. Time-events are those events which are scheduled to occur at specified points in time. The other type of events that can occur are state-events. These events are not scheduled, but occur when the system reaches a particular state.

According to Mize and Cox (11, p. 123), "the increase in the number, variety and complexity of system simulation studies has motivated the development of general simulation languages." These languages are designed to take advantage of the common features of simulation studies. They are intended to simplify the programming of the model so the analyst can concentrate on the model building. Emshoff and Sisson (4) state that a user wants a simulation language that: 1) facilitates model formulation; 2) is easy to program; 3) provides good error diagnostics; and 4) is applicable to a wide range of problems.

The languages that were considered include:

GASP - a set of subroutines in FORTRAN that provides useful functions in simulation [Pritsker (15)];

GPSS - a complete language oriented toward problems in which items pass through a series of processing and/or storage functions [Dunning (3)];

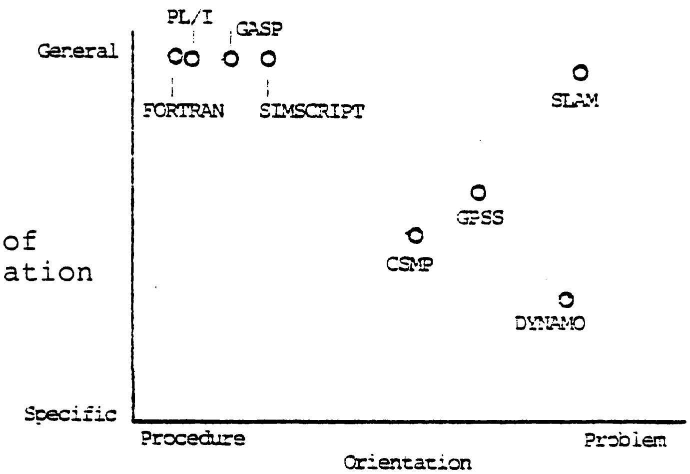
SIMSCRIPT - a complete language oriented toward event-to-event simulations in which discrete logical processes are common [Markowitz (9)];

CSMP - a complete language oriented toward the solution of problems stated as nonlinear, integral-differential equations with continuous variables [IBM Corp. (7)];

DYNAMO - a complete language oriented toward expressing micro-economic models of firms by means of difference equations;

SLAM - a complete language that makes use of networks and user written FORTRAN subprograms in both continuous and discrete modeling [Pugh (17)].

Emshoff and Sisson (4) classify these languages in Figure 1 in terms of orientation and scope or generality of application. The trade-off between generality (depth of application) and problem orientation is clear.



Source: J. R. Emshoff and R. L. Sisson, <u>Design and Use of Computer Simulation Models</u> (1970), p. 34

Figure 1. Classification of Languages Used For Simulation (Relative Only)

FORTRAN and PL/I are also included as examples of multipurpose languages in which any sort of state-change process can be described. GASP and SIMSCRIPT differ from FORTRAN and PL/I in that GASP and SIMSCRIPT are not complete languages. Both languages (GASP and SIMSCRIPT) are very general, and both can do anything that can be done in FORTRAN or PL/I.

GPSS is oriented more towards a particular kind of problem (queueing problems). Although it is problem oriented, GPSS has many features that permit it to be applied in a wide range of situations. Furthermore, the language can be augmented by subroutines written in Assembly language.

DYNAMO and CSMP are examples of languages oriented toward problems formulated in terms of nonlinear differential or difference equations. DYNAMO was developed for defining models of business and CSMP for engineering design applications. Neither language is very general, but both are quite useful in specifying simulation procedures for particular types of problems.

SLAM is probably the most versatile of all the language described. It can be as problem oriented as DYNAMO and as general as GASP or SIMSCRIPT. SLAM can simulate discrete, continuous, or combined discrete/continuous models. It can also interact with subroutines written in FORTRAN by the user to further extend the scope of the language.

Data Analysis

According to Mize and Cox (11, p. 84), "a sample is a subset of population, in simulation, a sample is usually utilized to represent the population as part of the input information into a more extensive model." Random samples of data must be taken to determine the behavior of the system. This data is usually then tested against a particular distribution for goodness-of-fit. Among different goodness of fit tests available, the Kolmogorov-Smirnov (K-S) test and the Chi-Square test are the most popular.

The K-S test [Massey (10)] consists of comparing the sample cumulative distribution functions with the theoretical cumulative distribution function at each sample observation. The test statistic is the maximum deviation between the two functions at any point in the sample. The statistic is then compared with a critical value, referenced by the size of the sample, and a chosen level of significance. At a given level of significance, the testing hypothesis may be rejected if the sample statistic is greater than the critical value.

In the Chi-Square test [Cochran (2)], the test statistic is the square of the summation of the observed data points in a particular cell minus the expected number of observations in that particular cell quantity squared, divided by the expected value for that particular cell. The test statistic is then compared with a critical value, referenced by the degrees of freedom and a chosen level of significance. As in the K-S test, the testing hypothesis may be rejected if the sample statistic is greater than the critical value.

Of the two tests, the K-S test is more powerful, and thus more likely to detect small differences in the actual and hypothesized distributions [Massey (10)]. The differences between the K-S test and the Chi-square test are beyond the scope of this paper; for further discussion, refer to Massey (10).

The literature review has dealt primarily with the theoretical aspects of what simulation is, the different types of simulation including the world views, the different types of simulation languages, and fitting data to distributions for the simulation. Later, these aspects of simulation will be integrated and applied to a real world model in an industrial environment.

Alternatives to Simulation

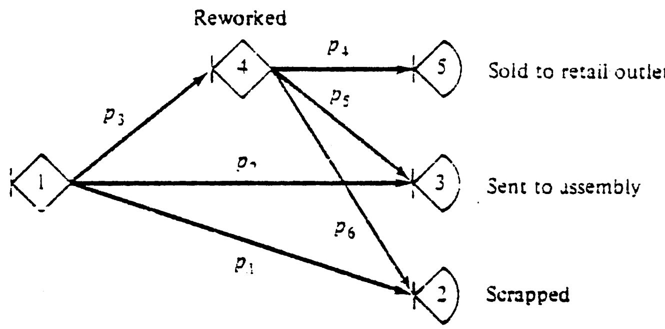
Simulation is a very useful tool in system analysis, however, simulation can be very expensive and time consuming. Also, some companies may not have a computer accessible that is large enough to handle simulation computer models. There are a number of analytical methods today that provide an alternative to simulation. Two such methods, GERT and CAN-Q, will be discussed.

GERT

GERT (Graphical Evaluation and Review Technique) is a procedure that combines the disciplines of flowgraph theory, moment-generating functions, and PERT to obtain a solution to stochastic problems [Phillips and Garcia-Diaz (14)].

Figure 2 represents a typical GERT network. The nodes of the network can be interpreted as states of the system. The arcs represent transitions from one state to another.

Such transitions can be viewed as activities characterized by a unique probability density function and a probability of realization.



Source: D Phillips and A. Garcia-Diaz, Fundamentals of Network Analysis (1981), p. 14

Figure 2. Typical GERT Network

Each node performs two functions, an input function which indicates the condition under which the node can be realized, and an output function which indicates the branching condition following the node realization.

Two types of nodes are associated with GERT (Figure 3). Type a is a deterministic output and type b is a probabilistic output node. The deterministic node is realized when any arc leading into it is realized under the condition that only one arc can be realized at a time. All arcs emanating from the node are then undertaken. The input to the probabilistic node is the same as the deterministic node, however, only one arc emanating from this node is realized.

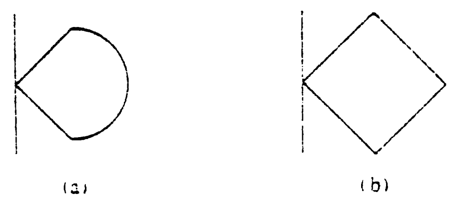


Figure 3. GERT Node Types

Time from node to node is described through moment-generating functions (Table I). These functions can be manipulated in such a way as to determine moments of the distribution of time spent in moving from one node to another. First, a W function must be calculated. The W function of a given arc is defined as the product of the probability of undertaking the arc and the moment-generating function of the duration of the activity represented by the arc [for W calculations of loops, loops of order n and a closed flow graph refer to Phillips and Garcia-Diaz (14)]. An overall value of the moment generating functions can be calculated through

$$M_e = W_i(s)/p_e$$

By then determining the jth partial derivative of $M_e(s)$ with respect to s, and setting s to zero, a mean can be obtained through

$$\mu_{je} = (d_j/ds_j)[M_e(s)]\Big|_{s=0}$$

In particular, the first moment about the origin, μ_{1e}, produces the mean network realization time while the variance of the network realization time is obtained by computing μ_{2e} and subtracting it from the square of μ_{1e}; that is

$$\sigma^2 = \mu_{2e} - (\mu_{1e})^2$$

TABLE I

MOMENT GENERATING FUNCTIONS

Type of Distribution	$M_E(s)$	Mean	Second Moment
Binomial (B)	$(pe^s + 1 - p)^n$	np	$np(np + 1 - p)$
Discrete (D)	$\frac{p_1 e^{sT_1} + p_2 e^{sT_2} + \cdots}{p_1 + p_2 + \cdots}$	$\frac{p_1 T_1 + p_2 T_2 + \cdots}{p_1 + p_2 + \cdots}$	$\frac{p_1 T_1^2 + p_2 T_2^2 + \cdots}{p_1 + p_2 + \cdots}$
Exponential (E)	$\left(1 - \frac{s}{a}\right)^{-1}$	$\frac{1}{a}$	$\frac{2}{a^2}$
Gamma (GA)	$\left(1 - \frac{s}{a}\right)^{-b}$	$\frac{b}{a}$	$\frac{b(b + 1)}{a^2}$
Geometric (GE)	$\frac{pe^s}{1 - e^s + pe^s}$	$\frac{1}{p}$	$\frac{2 - p}{p^2}$
Negative binomial (NB)	$\left(\frac{p}{1 - e^s + pe^s}\right)^r$	$\frac{r(1 - p)}{p}$	$\frac{r(1 - p)(1 + r - rp)}{p^2}$
Normal (NO)	$e^{sm + (1/2)s^2\sigma^2}$	m	$m^2 + \sigma^2$
Poisson (P)	$e^{\lambda(e^s - 1)}$	λ	$\lambda(1 + \lambda)$
Uniform (U)	$\frac{e^{sa} - e^{sb}}{(a - b)s}$	$\frac{a + b}{2}$	$\frac{a^2 + ab + b^2}{3}$

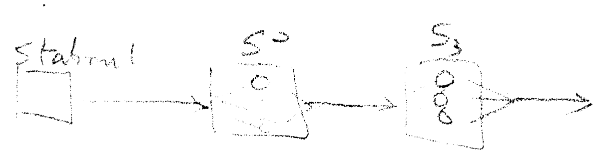
Source: D. Phillips and A. Garcia-Diaz, Fundamentals of Network Analysis (1981), p. 14.

GERT, as an alternative method to simulation, can be used if no computer is available. GERT, however, is only useful for small networks. GERT also requires an intricate understanding of the system. Distributions must be determined for service times, and the system must be networked. Thus, a GERT analysis may well require as much involvement as would simulation analysis. Finally, analysis of GERT must be done through manipulating moment-generating functions. These manipulations can be prone to many errors. While GERT is an alternative method to simulation, GERT can be as costly and time consuming as simulation.

CAN-Q

Another type of analytical method that can be utilized instead of simulation is CAN-Q. This tool was developed in the form of a computer program by James J. Solberg of Purdue University (20). CAN-Q is a mathematical model for analyzing work flow in a production system through queueing theory and Markov Chains. The computer program accomplishes all of the difficult computations involved in translating the natural description of a system, its resources, and the processes involved in converting raw materials to finished product.

To initiate CAN-Q, the user must simply input the number of stations, the mean service time of those stations, the number of services for each station, the number of transports, the mean time of transportation, the number of products and their routing, and the number of entities desired in the system. CAN-Q takes this information and



produces detailed information for each station and product type including where the bottlenecks are located. Sensitivity analysis is also provided by the system.

To run CAN-Q, the user does not need a deep understanding of the system that is being studied, this eliminates the need for model building. The CAN-Q program also is not very long and therefore can run on a microcomputer. The elimination of model building, the reduced data gathering, and less computer time considerably lowers the cost of the system analysis as compared to using simulation. However, CAN-Q is unable to provide a complete picture of system behavior over time as simulation would. CAN-Q also provides no information about short-term behavior or extremes of system behavior that simulation could provide.

CHAPTER III

STATEMENT OF THE PROBLEM

Southwest Tube Manufacturing is a manufacturer of cold drawn tubing used in pressure and mechanical applications. Figure 4 represents the general plant layout and material flow through the plant. Bundles of tubes are transferred from the yard containing inventories of raw tube hollows to a holding area previous to the treating tanks. Tubes are either (1) cleaned and phosphated, (2) tricked, or (3) cleaned and lubed in the treating tanks. Two overhead cranes are used to service these tanks. Each crane services one side of the tanks. The tubes that are cleaned and phosphated and tricked exit the system at this point and are put back into storage.

The cleaned and lubed tubes are then moved to the pointer by overhead crane to allow pointing of the tubes. Pointing allows the grippers on the cold-draw benches to grab the tube through the die.

The tubes are then taken to the three draw benches by crane. The draw benches draw the tube through a die and over a mandrel to a specified outside and inside diameter. Next the tubes are taken by overhead crane to the annealing furnace where at a specified speed and temperature, they are softened to a desired hardness.

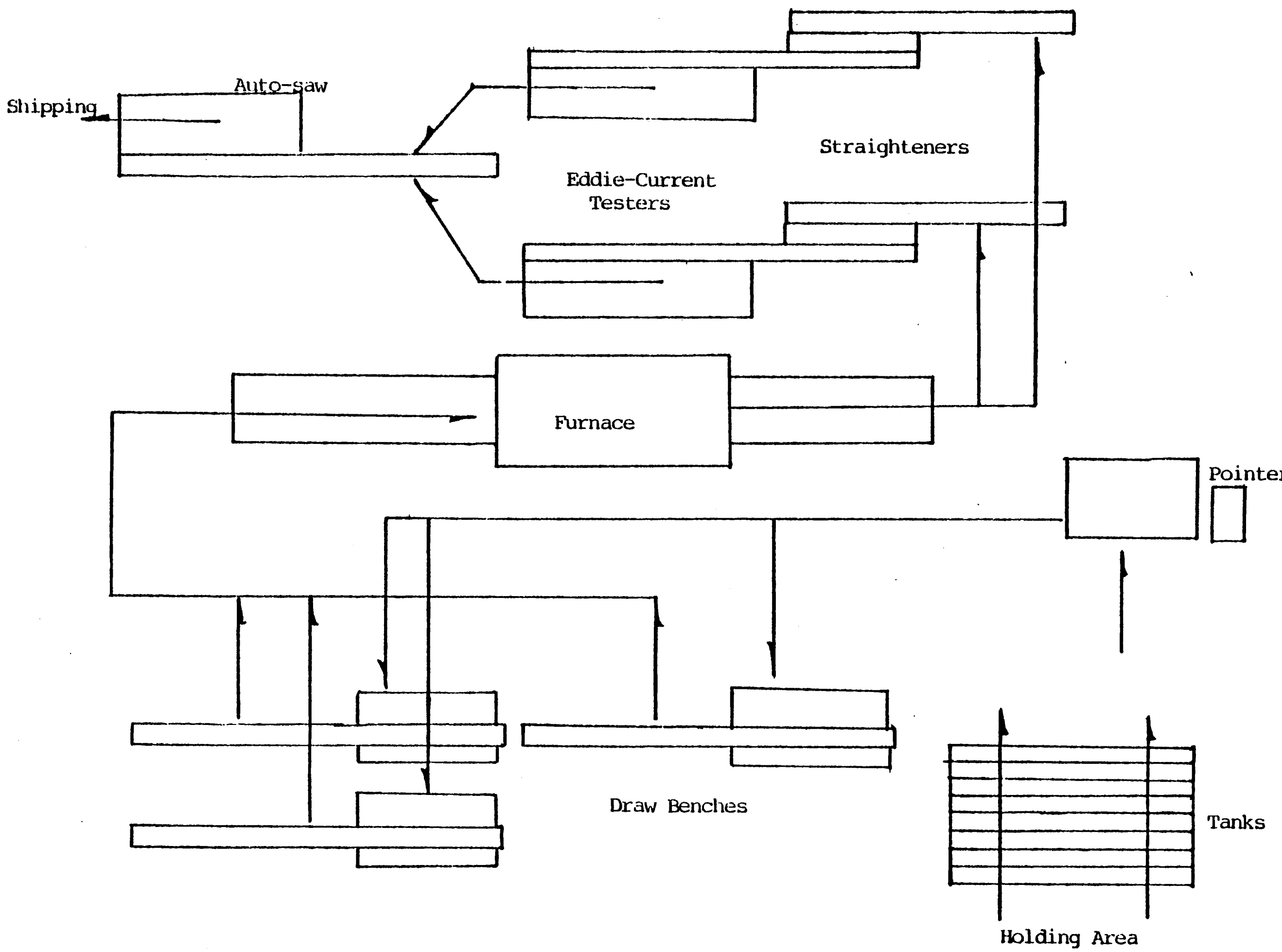


Figure 4. General Plant Layout and Material Flow

The tubes are then transferred by overhead crane to the straightener. The tubing is "straightened" by the straightener and is transferred by conveyer to the Eddie Current Tester, which uses a magnetic field to check for flaws in the tubing.

Final cutting is the next operation performed on the tubes. An overhead crane transfers the tubes from the Eddie Current Tester to the auto-saw. Here the tubes are cut to final length and bundled, then transferred by conveyers to the shipping area.

Within this material flow, a major bottleneck occurs at the tank area. Even though two separate cranes service the tanks, bundles of tubes cannot be processed through the tanks fast enough to keep up with the production rate of the rest of the plant. This problem causes the manufacturing floor to go "dry" before the end of a working shift.

The tank area (Figure 5) contains eight treating tanks. These tanks include: caustic, a cold water rinse, sulfuric acid, hot water, phosphate, another cold water rinse, a neutralizer, and a soap-type lube.

For a normal clean and lube operation, movement through the tank area starts at the caustic tank, which contains a detergent to start the cleaning process of the tubes. A "trip" of tubes (a trip can contain one to four bundles) is dipped into the caustic tank, raised and then drained. The tubes are then lowered into the caustic tank (cranes stay connected to the trips while soaking), where they sit for

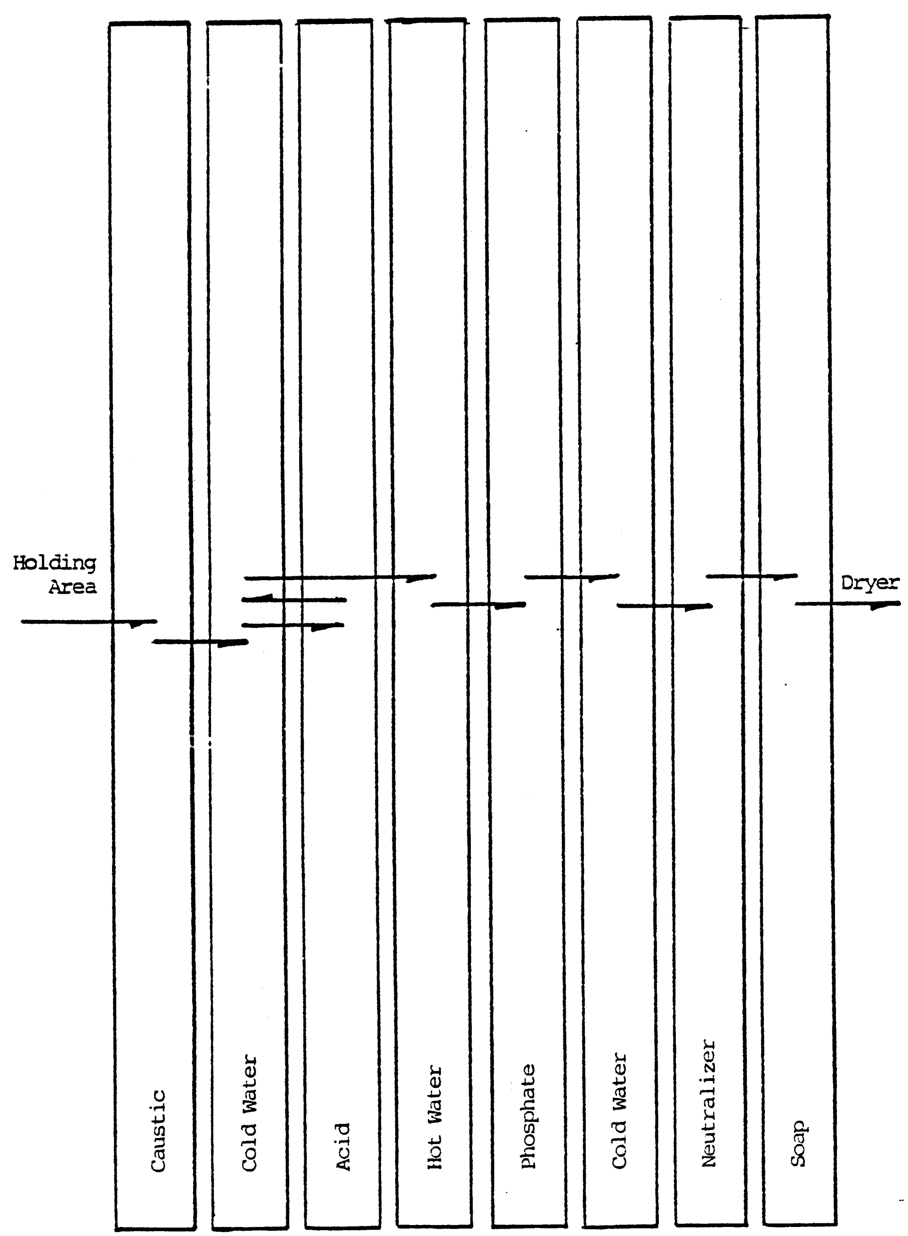


Figure 5. Tank System

five minutes before being rinsed and drained. The "trip" is transferred to the cold water rinse, where the tubes are dipped, raised, and drained. A transfer is then made to the sulfuric acid tank. The tubes are set in this tank until all scale is removed. They are then raised, drained, and transferred to the cold water rinse for redipping. The "trip" is taken to the hot water rinse where they are dipped and drained. The next tank is the phosphate tank; the phosphate acts as a secondary lubricant, and leaves a surface that the primary lube can bond to. The tubes are dipped, drained, and set into the phosphate for five minutes. The "trip" is then drained and moved to the second cold water rinse, where the tubes are dipped and drained. The next tank is the neutralizer. This is used to remove any positive charge from the phosphate that would prevent the primary lubricant from bonding to the surface of the tube. The tubes are dipped and drained in the neutralizer, then taken to the final tank where they are lubed. The lubricant is of the "soap" type which clings to the phosphate secondary lubricant. The tubes are dipped into the lube, drained, and then set into the tank for five minutes. The tubes are then drained and taken to the dryers located next to the tanks. The dryers dry the tubing in preparation for drawing.

The other two types of operations, cleaning and phosphate, and tricking, are less frequent than the cleaning and lubing operation. In the cleaning and phosphate operation, the neutralizer and lube tank are skipped. In the "trick" operation, the phosphate, second cold water rinse, neutralizer, and lube tanks are skipped.

In solving this problem, management first tried what is known as the "pinning off" technique. This entails pinning off a "trip" in a tank. The operator then leaves that "trip" to go get another "trip". The operator would then "pin-off" that trip and get "trip" or move the previously "pinned-off" set of tubes. This type of approach was used to increase utilization time of the crane. This approach was abandoned because the time it took to pin-off was greater than the greatest time allowed in any one tank and actually decreased the efficiency of the tanks and produced a poorer quality lube because of violating time constraints in certain tanks.

Management is currently considering adding two more cranes to the system. They want to know how many more "trips" can be produced by adding these cranes. Management also wants to know the net present value of the project for one, three, and five year periods.

The problem could be approached as a transportation problem using the cranes as transports and the tanks as destinations. However, the system is subject to random variations, and there is already a set pattern moving through the tanks. This causes the transportation method to be useless.

Because of the complexity of the problem, simulation appears to be the best tool.

The first step in simulating the system was data collection. This step was accomplished by observing and collecting pertinent data from the system. This data includes different types of trips, the breakdowns that occur, time spent in the tanks, and arrival times for bales of tubing. This data was collected from tank reports and actual observation of the system.

After the data was collected, the system was modeled in SLAM. In this stage, boundary lines were determined for the system, inputs and outputs were limited to what was pertinent to the system, and a SLAM network developed for the model. The data collected from the system was then organized into distributions. This was accomplished with a FORTRAN program developed and modified from Phillips (13), utilizing the K-S test.

The model was then validated by comparing the outputs to the real system. This was done with the Turing test [Shannon (19)], which involved showing the output from the real system and the output from the simulation to someone who is intimately familiar with the system, and asking him to differentiate between the two sets of outputs. If he succeeds, a question is raised on how the difference was noted. This provides insight on what might be wrong with the model. Finally, a t-test was performed on the model output, comparing the model outputs with the system outputs.

The next step involved adding two more cranes to the model. An economic analysis was then performed on the output to see if adding the cranes was profitable. This was done by estimating the total profit per "trip." A tonnage was estimated per trip, and a total profit per ton was calculated. A present value was then calculated for periods of one year, three years, and five years.

After the simulation analysis, CAN-Q was applied to the tank problem. A comparison was made of the CAN-Q output to the real system and the simulation output to determine the accuracy of CAN-Q. This was accomplished by determining a confidence interval of the output rate of the system from the simulation output. This interval was compared with the output rate calculated by CAN-Q. From this information it was determined which type of method was more desirable in this type of production situation, CAN-Q, which is less expensive and faster to develop than simulation, or simulation which reflects the system variability and is more accurate than CAN-Q.

CHAPTER IV

DATA COLLECTION AND ANALYSIS

The first phase in the simulation of the tank system entailed observation of the tanks to determine the boundaries of the system and the data that needed to be collected for the system. The next step consisted of collection, analysis and hypothesis testing of this data so that a manageable statistical description of the system could be made.

Observation and Data Collecting

Through observation of the system, it was found that data needed to be collected on movement time of the cranes, dipping time in the various tanks, time per trip in the acid tank, time per trip in the dryer, and hooking and unhooking times per trip. Also needed was the type of operation traveling through the tanks, the number of breakdowns, and the time the cranes are down.

Collection of the movement time between tanks was accomplished with a stopwatch. Timing was initiated when horizontal movement started. Timing was stopped when horizontal movement ceased. Table II represents the movement times between all tanks. These times are averages of 20 observatons taken of the tanks.

TABLE II

MOVEMENT TIME BETWEEN TANKS

Staging Area to Caustic	.12 minutes
Caustic to Cold Water Rinse	.0498 minutes
Cold Water Rinse to Acid	.075 minutes
Acid to Cold Water Rinse	.075 minutes
Cold Water Rinse to Hot Water Rinse	.30 minutes
Hot Water Rinse to Phosphate	.112 minutes
Phosphate to Cold Water Rinse	.114 minutes
Cold Water Rinse to Neutralizer	.036 minutes
Neutralizer to Soap	.100 minutes
Soap to Dryer	.100 minutes
Dryer to Staging Area	.948 minutes

Dipping times were collected by both the operator and myself. Figure 6 contains the form used in the data collection. Dipping times were taken at random for different size tubing and recorded on the data sheet. Total times in the acid tank and on the dryer were also taken through this method and recorded on the data sheet.

Hooking and unhooking times were collected by observation of the operator. From these times a standard was calculated for the operator. A standard was also developed for a "pinning off" operation. This standard was done for a two crane two operator system which will be described later in this chapter. All standard times are located in Table III. Finally, the type of operation, the number of breakdowns and the length of down time was collected through the Tank Summary Sheet (Figure 7).

Date: 10-12-83

	W.O. #	Bale #	Time	W.O. #	Bale #	Time	W.O. #	Bale #	Time
Dipping Caustic	D10-215-3	#2	52 sec.	D10-389-3	#1	51 s.	D10-389-3	#6	69 s.
Dipping Cold Water			33			33 s.			53
Dipping Acid			50			50			66
Dipping Hot Water			33			33			53
Dipping Phosphate			50			52			(crossed out) 70
Dipping Neutralizer			60			52			77
Dipping Lube			51			50			68.
Acid Time			9min.			15min			17min.
Scale (Light, Medium, Heavy)			Med.			Med.			Med
Drying Time			10 min			5min.			5 min

Figure 6. Form Used for Dipping Times

Downtime Code: 1) Breakdown
2) Tank Cleaning
3) No Material

A/H 11.25
D.T.
Prod Time 11.25

SOUTHWEST TUBE MANUFACTURING COMPANY

COLD DRAW PRODUCTION SUMMARY
TANKS

DATE: 9-13-83 SHIFT: II OPERATOR: [illegible] SUPERVISOR: R. [illegible]

	WORK ORDER #	BALE #	START	FINISH	# PIECES	PROCESS LUBE	CLEAN PHOSPHATE	CLEAN TRICK
1	D9-4113-MU	9	9.P	✓	26	Y		
2	D9-310-3	8	✓	✓	20	✓		
3	D9-310-3	14	✓	✓	20	✓		
4	D9-310-3	23	✓	✓	13	✓		
5	D9-212-3 MU	(1-2)	✓	✓	30 TOTAL	Re-lube		
6	D9-105-3 MU	1	✓	✓	55	✓		
7	D9-150-3 MU	1	✓	✓	19	✓		
8	D9-310-3	7	✓	✓	20	✓		
9	D9-310-3	6	✓	✓	20	✓		
10	D9-310-3	13	✓	✓	20	✓		
11	D9-310-3	2	✓	✓	20	✓		
12	D9-310-3	5	✓	✓	20	✓		
13	D9-310-3	10	✓	✓	20	✓		
14	D9-310-3	12	✓	✓	20	✓		
15	D9-310-3	21	✓		20	✓		
16								
17								
18								
19	14 Bales							
20	14 Runs							
21								
22								
23								

COMMENT:

Figure 7. Tank Summary Report

TABLE III

STANDARD TIMES FOR HOOKING AND UNHOOKING

Staging Area	6.71 minutes
Pinning Off	2.00 minutes
Drying Area	2.30 minutes

Data Analysis and Hypothesis Testing

Analysis and hypothesis testing was done on the dipping times in the tanks, acid soaking time, and drying time of the tubes. All hypothesis testing was accomplished using the K-S test. A program initially developed by Phillips (13) was used for all hypothesis testing. The program was modified for user interaction, data insertion, and histogram manipulation for use on the Hewlett-Packard/3000. Appendix A contains the data collected, their respective histograms, and detailed results of the K-S test.

Table IV contains the final accepted distributions and parameters by the K-S tests.

The mean times differ for dipping in the various tanks because of the different properties of the liquids in each tank, such as viscosity and density. Dipping follows distributions because of the effects of the inside diameter and the length of the tubing. A larger inside diameter and a longer tube requires more time to be spent in filling and draining the tubes. The different degrees of scale on the tubes cause a distribution in the acid tank. When soaking in the acid, more time is needed to remove heavy scale. Drying times differ due to the number of pieces in a trip, the length of the tubes, and the inside diameter of the tubes. A longer period of time is needed for drying larger surface areas. Tonnage per trip was taken from the Tank Summary Report (Figure 7) and the Work Order (Figure 8).

TABLE IV

DISTRIBUTIONS FOR THE TANK SYSTEM

Type	Distribution	Parameters
Caustic Dipping	Normal	.014 mean, .0035 variance
Cold Water Dipping	Normal	.0119 mean, .0035 variance
Acid Dipping	Normal	.0139 mean, .0034 variance
Acid Soak	Normal	.1989 mean, .0034 variance
Hot Water Dipping	Normal	.012 mean, .0034 variance
Phosphate Dipping	Normal	.0145 mean, .0048 variance
Neutralizer Dipping	Normal	.0159 mean, .00384 variance
Soap Dipping	Normal	.0139 mean, .00346 variance
Drying	Exponential	.1673 mean
Tons/Trip	Gamma	.42017 alpha, 3.183 beta
Breakdown Length	Exponential	1.023 mean

Tonnage was calculated by multiplying the weight per foot of the tubes in the trip by the length of the tubes located in the Work Order, and multiplying this number by the number of pieces per trip taken from the Tank Summary Report.

SOUTHWEST TUBE MANUFACTURING COMPANY

INTERNAL WORK ORDER

Pcs.	FOOTAGE	O.D.	1 Wall	Length	Specification	Wt./Ft.
	5000	.500	310	17-24'	ASTM A 513-5	.4214

STEEL APPLICATION

Pcs.	O.D.	Wall	Length	Heat	Grade	Bale	Drawn Length		Wt./Ft.
23	.820	.115	12 6	S8247W	W1020	1	16 2	22 4	.8659
105	.750	.120	17 0	S8202W	W1020	2	19 11	29 10	.8074
82	.750	.120	21 0	S8202W	W1020	3	24 10	37 6	.8074
13	.750	.122	12 0 RL	S8240W	W1020	4	14 0	20 8	.8183
	3208#								
							① 4681		
							② 7003		

POINTER

Bales	Die 1	Die 2	Die 3	Bales	Die 1	Die 2	Die 3		Bales	Die 1	Die 2	Die 3
1-4	.677	.575						PROCESS ANNEAL	1-4	.505	.477	

Bales 1-4 both Passes

COLD DRAW

Pass	Die	Mandrel	Drawn O.D.	O.D. Tol.	Drawn Wall	Wall Tol.	% Red.	Wt./Ft.
1	.6263	—	.626	—	.115/.122	—	27% 19% 20%	.558/.65
		Cut Points + Process Anneal						
2	.502	.307	.502	.500/.505	.0975	.305/.310	33%	36% .4212
		TRY BALES 2-4 in one Pass first						

Process Cutting ☒ N/R

Process Annealing 1650 °F @ 5'6" FPM 89 Tubes Per Row 19,296 Lbs. Per Hr

Final Anneal ☐ N/R 1000 °F @ 5'2" FPM 89 Tubes Per Row 11,606 Lbs. Per Hr

Cycle Anneal: Zones °F/Zones °F/Zones °F

Hardness Tests 1 Tube per row ☒ B 80 Min./ ☐ B Max./ ☒ For Internal Use Only

Date 11-9-82

Written By Linda

Approved By Dave

W.O. # D11-608-2

Page 1 of 2

Figure 8. Work Order

Finally, calculation of the probability of a breakdown, the probability of a lube operation, phosphate operation, and a trick operation was made through the Tank Summary Report. Tank Summary Reports for the previous three months were used to calculate these probabilities. Breakdowns, lube operations, phosphate operations, and trick operations were tallied and divided by the total number of trips. The probability of a breakdown is 0.17; the probabilities for a lube, phosphate and trick operation are 0.89, 0.043, and 0.067, respectively.

CHAPTER V

MODELING OF THE TANK SYSTEM

Three different versions of the tank system were developed for Southwest Tube. These versions include the present system, a two crane one operator system, and a two crane two operator system. Each of these models has the same two major assumptions. The first assumption is that there is an endless supply of tubing for trips. It was determined from the production planning department that the tanks never wait for material. Another major assumption made was that there is always room for more trips in the dryer.

This chapter describes in detail each system and how each system is modeled.

Present System Model

The present system, as previously described in Chapter III, is modeled completely in network SLAM (Appendix B). Presently, two cranes work the system. Each crane has responsibility for one side of the tank system. Since these cranes operate independently, only one crane will be considered in the network.

The model consists of two major networks. The first network consists of the actual operation of the crane through the tanks. A create node creates one entity to run through the model. The entity is then determined to be a clean and phosphate trip, a tricked trip, or a clean and lube trip through probabilistic branching. All major attributes are then assigned to the entity. These attributes contain all service times through the tanks and the time an entity starts the tank operation. The entity then goes through the various services of the tanks, branching off to particular nodes depending on what type of operation is assigned to the entity. Resource gates throughout the system stop the flow if any breakdown should occur (breakdowns are modeled in the second network). The entity is then split at the end of the network after the entity is placed in the dryer for service. One entity continues service throughout the dryer and is terminated. The other entity is taken back to the beginning of the network after a crane move time to start through the system again. COLCT nodes are used at the end of the network to allow collection of the time in the system for each entity.

The second network consists of all breakdowns for the crane system. This network starts with a create node to loop one entity through the system.

Through probabilistic branching, it is determined if a breakdown will occur for a particular shift. A breakdown time and a service time are then determined for that particular breakdown. When a breakdown does occur, the resource CRI is closed until the repairs are made. The resource gate is then opened so the cranes can continue through the system. The entity in the breakdown network then loops to the beginning for the next 12 hour shift.

Two Crane One Operator Model

This system is similar to the original system except for the addition of another crane (Appendix C). In this system one operator operates the two cranes through the tanks. One crane is moved while the other is in a soaking operation. This model includes four networks - one network for each crane, and one network for breakdowns of each crane.

Major problems arise in the modeling of the two crane system due to interference of the two cranes. This problem is solved by determining which crane will be ahead of the other and keeping it that way through a series of resources and gates controlled in the networks representing each crane.

The first network represents the crane that is always in front. The network is the same as the original model except for the resources and gates used to control interference. Gates are used to prevent movement of the other crane when a crane is being manipulated. Another set of gates and resources is used to prevent the overtaking of the first crane and to prevent the use of the same soaking tank. These gates and resources are used in front of the first cold water tank (because of the back-tracking out of the acid tank), in front of the phosphate tank, and in front of the soap tank. Gates and resources are also placed in the branching of the network for the trick trip and the clean and phosphate trip to prevent the second network from overtaking the first network. The ending of the two crane networks is similar to the original network except for the waiting of the first crane network for the second crane network to finish. This allows the operator to move the cranes together back to the beginning of the tanks.

The two networks that run the crane breakdowns are the same as the present system's crane breakdown network. Gates control resources in the corresponding networks to allow breakdowns of the two crane systems.

Two Crane Two Operator Model

This model utilizes three networks - one for the two cranes, and two for the breakdown of the cranes (Appendix D). Figure 9 represents the assignment of the two cranes to their prospective areas of the tank. It is desirable to have an even balance of time in the tanks for each assigned crane area. Given the present means and time in the soaking tanks, the hot water tank seems to be the best prospective dividing point for the crane assignment areas. The hot water tank will be the "pin-off point" for the cranes. The crane assigned to the first set of tanks in the sequence will "pin-off" a trip in the hot water tank after completion of the tank procedures in its area. This crane will then

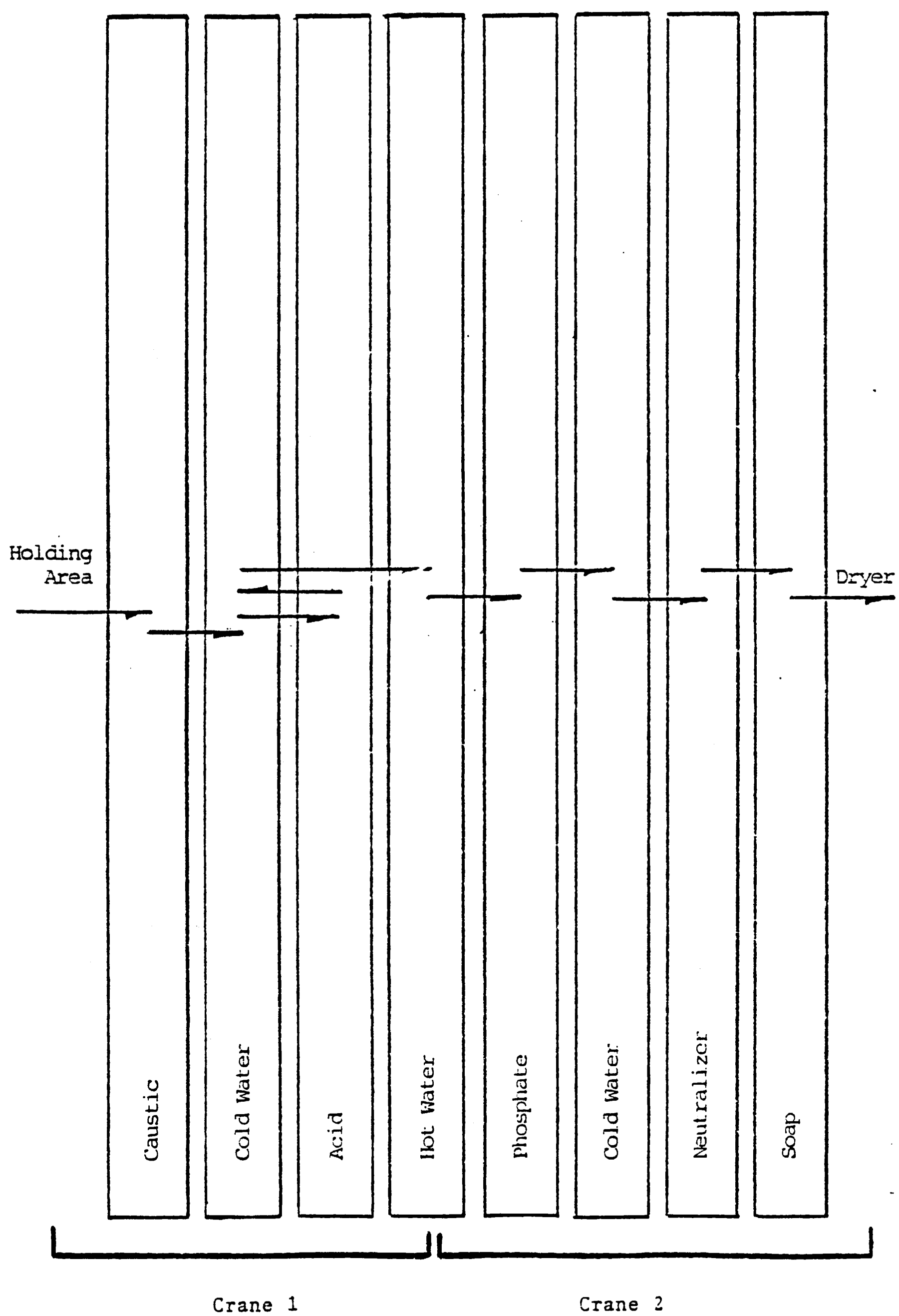


Figure 9. Crane Tank Assignment

hook up with the bale in the hot water tank and complete the tank procedures in its assigned area. This crane will then return to the hot water tank to pick up another trip.

The SLAM model is similar to the Present System Model. The model is the same as the Present System Model until the hot water tank. At this point a resource is added to avoid interference between the two cranes. This resource requires the first crane to wait for the hot water tank to be empty. When the tank is empty a "pin-off" operation can then be performed. The entity is then split to allow the crane to return to the start of the network to pick up a new trip. The other entity continues on through the second crane area. This area begins with a resource to allow the trip to wait for the second crane to finish procedures with the previous entity. The entity then is serviced by the remaining tanks. After service, the entity is split. One entity goes through the dryer where statistics are collected and where the entity is terminated. The other entity releases the resource corresponding to waiting in the hot water tank after move time for the second crane. The entity is then terminated.

The two crane breakdown networks are exactly the same as the breakdown networks in the Two Crane One Operator Model.

CHAPTER VI

TANK SIMULATION ANALYSIS

This chapter contains a discussion of each type of model and its outputs. From these outputs confidence intervals are calculated. These intervals will be discussed and analyzed.

Present System Model

The Present System Model was run for a total of 3600 hours (30 12 hour shifts). The model was started in steady-state. Outputs for the 10 runs is located in Appendix E.

Present System Output

Table V represents the output for all 10 runs of the Present System Model. Trip output per run ranged between 433 and 446 trips, with an average of 439.6 trips. This caused the average output of trips per shift to range between 14.43 trips to 14.87 trips, with an average of 14.65 trips. The tank time (time through the tank system without the dryer) ranged between 0.81 and 0.83 hours, with an average of 0.82 hours. Total time in the system (time in the tank system including dryers) ranged between 0.94 and 0.98 hours, with an average of 0.97 hours. The number of breakdowns in the system contained a low value of 0 and a

TABLE V

OUTPUT FOR PRESENT SYSTEM MODEL

Run	1	2	3	4	5	6	7	8	9	10	Avg.
Trip Output	442	437	433	443	433	441	441	436	446	444	439.6
Output/Shift	14.73	14.57	14.43	14.76	14.43	14.7	14.7	14.53	14.87	14.8	14.65
Tank Time	.81	.82	.83	.81	.83	.82	.82	.82	.81	.81	.82
Total Time	.96	.98	.96	.94	.98	.97	.98	.97	.95	.96	.97
Number of Breakdowns	5	4	5	7	7	4	4	8	0	6	5
Ton Output	589	599.7	557.6	621.7	593	616.5	577.5	593.8	571.3	567	588.7

high value of eight breakdowns, with an average of five. Ton outputs ranged from 557.6 to 621.7 tons, with an average of 588.7 tons.

Present System Confidence Intervals

A confidence interval was calculated for all the parameters in Table V to provide a more accurate view on exactly where the range of values lie for each type of parameter. Using a 95 percent confidence interval and the equation

$$\bar{X}(n) \pm t_{R-1,.025}\sqrt{\frac{s^2(n)}{n}}$$

computations were made for the set of 10 runs. This equation assumes normality. X (n) is the mean of the distribution, s^2 is the variance, t_{R-1} is the factor corresponding to a 95% confidence interval.

Figure 10 shows the confidence interval for the trip output. It can be stated with 95% confidence that the interval of 429.78 and 449.4 contains the true mean for 30 shifts.

Figure 11 represents the confidence interval for tank time. With tank time, there is 95% confidence that the interval of 0.80 and 0.837 includes the true mean of time spent in the tanks.

The confidence interval for total time in the system including the dryer is represented in Figure 12. There is a

95% confidence that the interval bracketed by 0.94 and 1.00 contains the true mean of total time in the system.

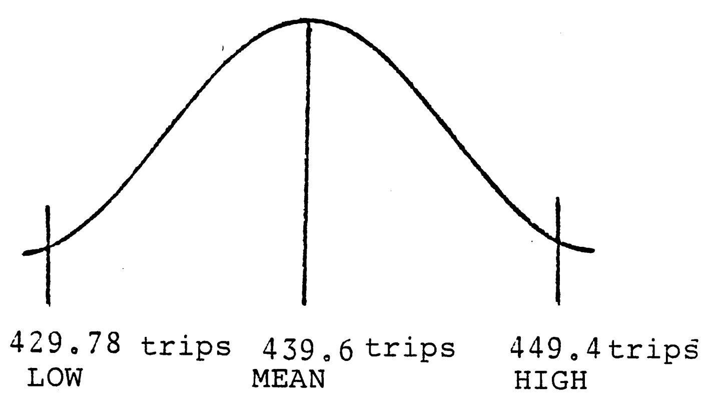


Figure 10. Confidence Interval for Trip Output in the Present System Model

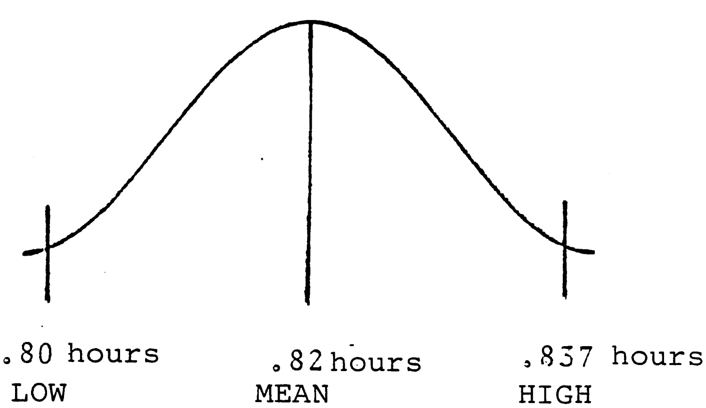


Figure 11. Confidence Interval for Tank Time in the Present System Model

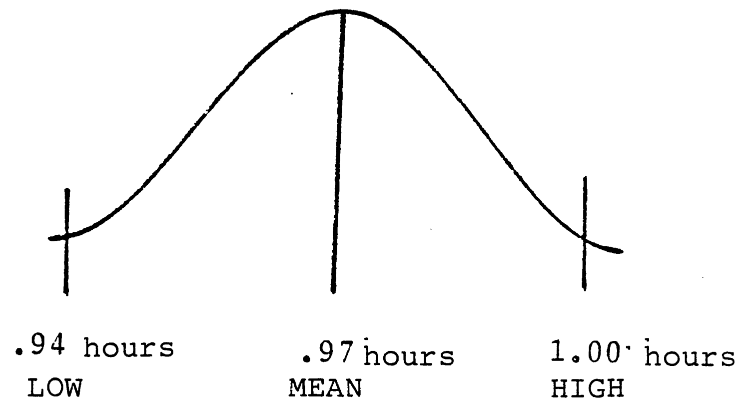


Figure 12. Confidence Interval for Total Time Spent in the Present System Model

The number of breakdowns confidence interval is represented in Figure 13. It can be stated that there is a 95% confidence that the interval of 0.15 and 9.85 encases the mean number of breakdowns for a 30 shift period.

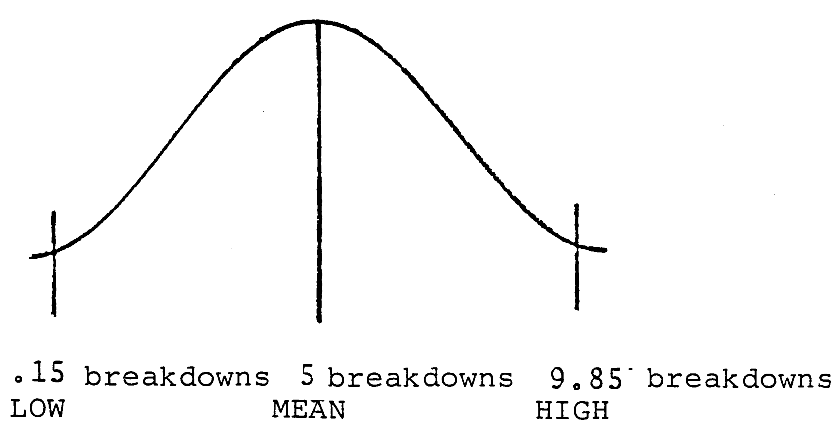


Figure 13. Confidence Interval for Breakdowns of the Present System Model

Figure 14 represents the confidence interval for ton output. It can be stated that there is a 95% confidence that the interval of 544.1 and 633.33 bounds the true mean of tons for a 30 shift period.

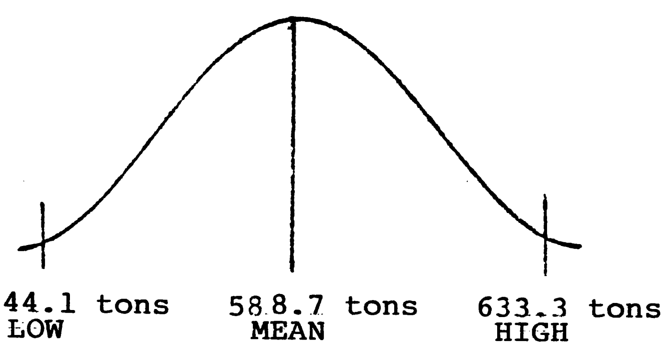


Figure 14. Confidence Interval for Ton Output of the Present System Model

Present System Final Analysis

To validate the simulation, a t-test was performed between the trip output and data collected for 10 different sets of 30 shifts each. Table VI represents the final results of this t-test.

Since t_o is less than the critical t-test value of $t_{18,.025}$, the hypothesis that the mean of the actual output equals the simulation output cannot be rejected. This is a good indication that the model is valid.

TABLE VI

T-TEST OF TRIP OUTPUT VS. ACTUAL OUTPUT

Simulation Output	Actual Output
442	420
437	452
433	448
443	440
433	443
441	439
441	440
436	444
446	442
444	440

$\mu_1 = 439.6$ $\mu_2 = 440.8$

$S_1^2 = 18.84$ $S_2^2 = 63.16$

$H_o: \mu_1 = \mu_2$

$H_1: \mu_1 \neq \mu_2$

$$Sp^2 = \frac{(10-1)\ 18.84 + (10-1)(63.16)}{8} = 92.31$$

$$t_o = \frac{440.8 - 439.6}{92.31\sqrt{1/10 + 1/10}} = .029$$

$t_{.025,18} = 2.101$

$t_{.025,18} > t_o$

Cannot Reject H_o

Validation was also made through the Director of Cold-Draw Operations. Utilizing the Turing Test, a set of output from the actual system of the number of trips per shift and output of trips per shift was given to the Director of Cold-Draw Operations. No distinction could be made, thus validating the model further. The director was also given a list of mean times in the tanks and times taken with a stopwatch by the tank operator of time through the system. The director could not tell the difference between these times, either.

The data showing the number of breakdowns also seem to be valid. If there is a 17% chance of a breakdown during any shift, for a 30 shift period there should be approximately 5.1 breakdowns. The ton output also seems correct with a value of 588.7 tons. The average number of tons per shift is 1.337; multiplying this by the total number of trips, a number of 587.7 tons is obtained. This is well within the 95% confidence interval calculated for tons.

From the output, it seems that this is an extremely valid and accurate simulation model of the tank system. The next two sections deal with the addition of two cranes to the model and their effect on the output.

Two Crane One Operator Model

The Two Crane One Operator Model was run for a total of 360 hours, or 30 shifts as was the Present System Model.

Output for the 10 runs is located in Appendix F.

Two Crane One Operator Model Output

Table VII represents a summary of the output for all 10 runs. Trip output ranged between 769 and 797 total trips, with an average of 779.3 trips per 30 shift period. This caused the output per shift to range between 25.6 and 26.57 trips per shift, with a mean of 26 trips. The tank time for crane one had a low of 0.88 hours and a high of 0.91 hours, with a mean of 0.897 hours. The total time in the system including the dryer ranged between 1.04 and 1.1 hours, with an average of 1.06 hours. Tank time using crane two had a low of 0.90 hours and a high of 0.93 hours, with a mean of 0.92 hours. Total time in the system through crane two ranged between 1.05 and 1.1 hours, with a mean of 1.09 hours. The number of breakdowns for crane one had a low of 0 breakdowns, a high of 10 breakdowns, and an average of 5.2 breakdowns. The number of breakdowns for crane two ranged between 3 and 9, with a mean of 6.1. Ranges for the total ton output of the system fell between 1020 and 1111 tons, with a mean of 1053.3 tons.

Two Crane One Operator Confidence Intervals

A confidence interval of 95% is calculated for all parameters as in the Present System Model to provide a more accurate view of the range of values for the Two Crane One Operator Model.

TABLE VII

OUTPUT FOR TWO CRANE ONE OPERATOR MODEL

Run	1	2	3	4	5	6	7	8	9	10	Avg.
Trip Output	781	788	773	777	773	773	769	796	776	786	779.3
Output/Shift	26	26.3	25.8	25.9	25.8	25.8	25.6	26.6	25.9	26.2	26.00
Tank Time System 1	.90	.90	.90	.89	.91	.903	.91	.88	.89	.89	.897
Total Time System 1	1.1	1.04	1.06	1.07	1.06	1.06	1.07	1.05	1.05	1.06	1.06
Tank Time System 2	.92	.91	.92	.92	.93	.93	.93	.90	.92	.91	.92
Total Time System 2	1.1	1.05	1.1	1.1	1.1	1.08	1.1	1.07	1.09	1.09	1.09
Number of Breakdowns System 1	3	10	4	4	7	5	9	0	5	5	5.2
Number of Breakdowns System 2	6	7	5	7	7	9	3	5	7	5	6.1
Ton Output	1046	1059	1068	1040	1020	1020	1083	1111	1053	1033	1053.3

Figure 15 represents the confidence interval of trip output in the system for this model. There is a 95% confidence level that the interval of 760.7 and 798 embraces the true mean for the total number of trips for a series of 30 shifts.

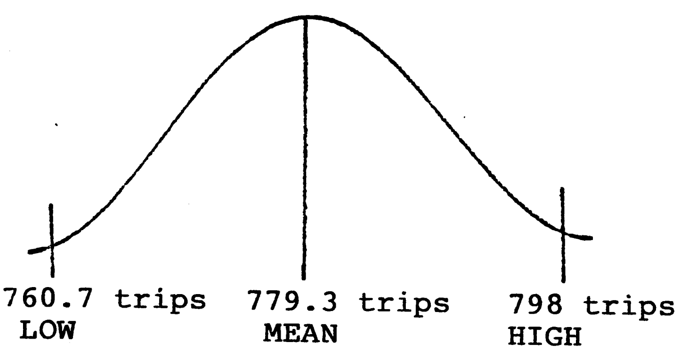


Figure 15. Confidence Interval for Trip Output of Two Crane One Operator Model

A 95% confidence interval for tank time using crane one is represented in Figure 16. It can be stated that there is a 95% confidence that the interval of 0.877 and 0.917 contains the true mean of tank time for crane one.

Figure 17 represents the 95% confidence interval for total time using crane one. There is a 95% confidence that the interval 1.025 and 1.094 includes the true mean for total time in the system.

Figure 18 represents the confidence interval for tank time using crane two. There is a 95% confidence that the interval of 0.897 and 0.942 contains the true mean of tank time using crane two.

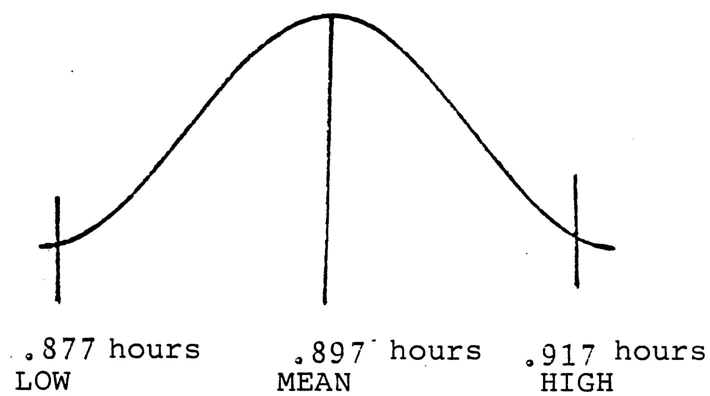


Figure 16. Confidence Interval for Tank Time of Crane One of Two Crane One Operator Model

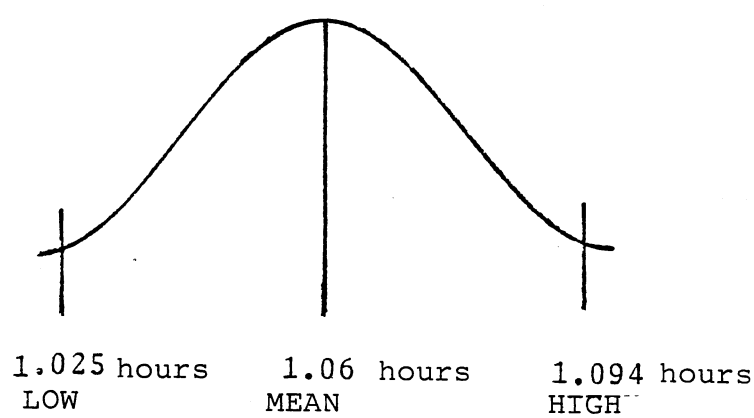


Figure 17. Confidence Interval for Total Tank Time of Crane One of Two Crane One Operator Model

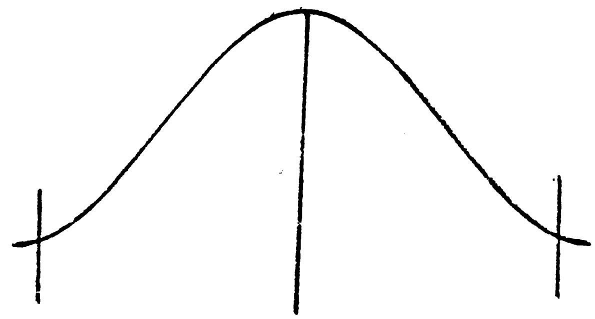


Figure 18. Confidence Interval for Tank Time of Crane Two of Two Crane One Operator Model

Total time in the system utilizing crane two is represented by the confidence interval in Figure 19. There is a 95% confidence that the interval of 1.053 and 1.126 brackets the true mean of total time in the system.

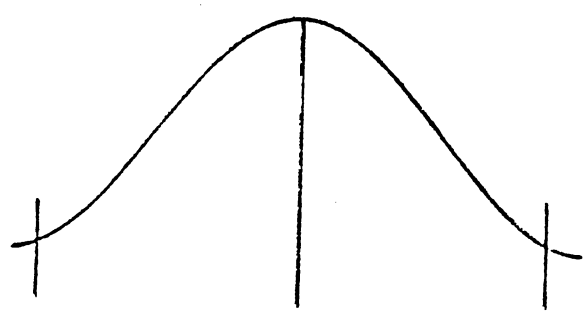


Figure 19. Confidence Interval for Total Tank Time of Crane Two of Two Crane One Operator Model

Figure 20 represents the confidence interval for the number of breakdowns for crane one. It can be stated that there is a 95% confidence that the interval of 0 and 11.4 the true mean for the number of breakdowns for a 30 shift period.

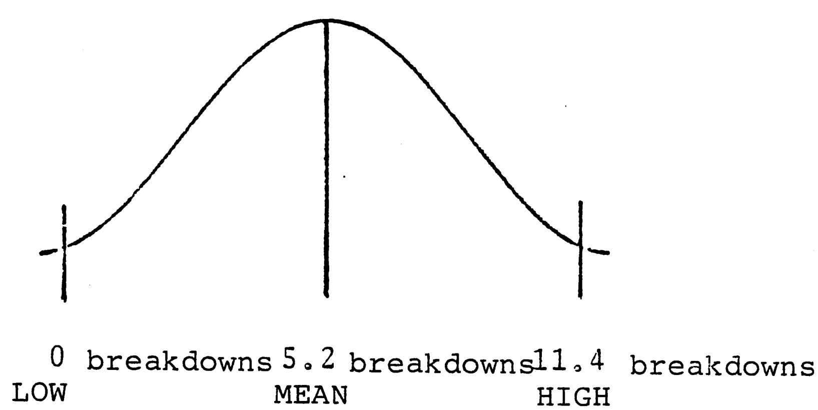


Figure 20. Confidence Interval of Breakdowns for Crane One for Two Crane One Operator Model

The confidence interval for the number of breakdowns of crane two is represented in Figure 21. There is a 95% confidence that the interval of 2.53 and 9.67 includes the true mean of breakdowns for crane two for a 30 shift period.

Figure 22 represents the 95% confidence interval for the ton output of this model. It can be stated that for a 30 shift period the interval of 992.1 and 1114.5 contains the true mean for number of tons produced by the system.

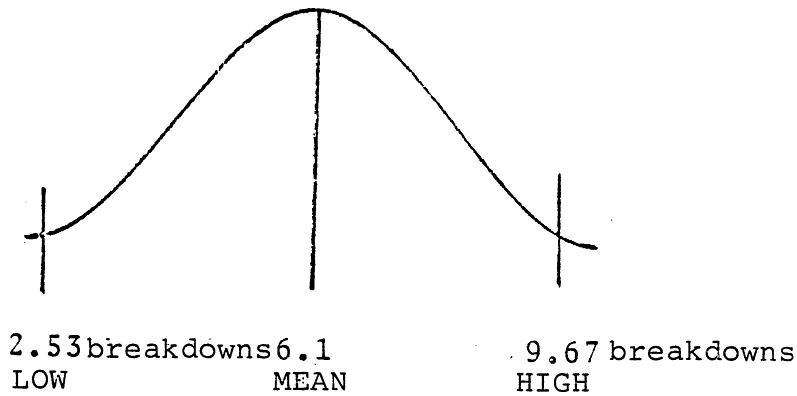


Figure 21. Confidence Interval of Breakdowns for Crane Two for Two Crane One Operator Model

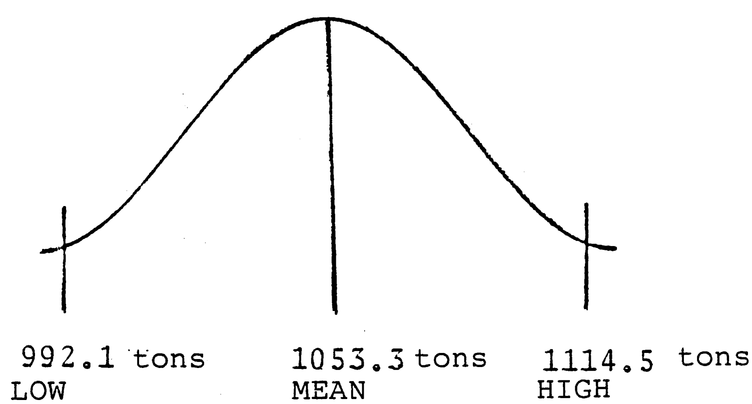


Figure 22. Confidence Interval of Ton Output for Two Crane One Operator Model

Gate Analysis of the Two Crane One Operator Model

Gate statistics are located in Table VIII for the 10

TABLE VIII

GATE STATISTICS FOR TWO CRANE ONE OPERATOR MODEL

Run	1	2	3	4	5	6	7	8	9	10	Avg.
MOV	.426	.467	.3799	.3754	.4292	.4159	.4217	.4203	.4076	.3780	.4121
SC2	.633	.638	.6242	.6280	.6393	.6401	.6324	.6364	.6367	.6274	.6336
SC1	.526	.521	.5366	.5274	.5285	.5342	.5312	.5233	.5330	.5308	.529
C2	.897	.898	.8951	.8957	.9009	.8875	.8824	.8952	.9002	.9015	.895
P2	.914	.913	.9167	.9185	.9178	.9164	.9135	.9173	.9162	.9161	.916
SO2	.878	.879	.8833	.8840	.8704	.8716	.8843	.8819	.8782	.8765	.879
ACID	.705	.693	.7118	.7114	.7077	.7178	.7138	.6997	.7145	.7086	.708
PAS1	.699	.698	.7221	.7238	.6974	.7082	.7176	.7228	.7123	.7126	.711
PAS2	.872	.873	.8769	.8786	.8626	.8659	.8741	.8755	.8733	.8692	.872

runs of this system. It is useful to take a look at these statistics to see how the system is operating in the case of crane interference for this model.

The MOV gate allows crane one to wait for crane two before moving back through the system. This gate is open an average of 41% of the time. This means that 59% of the time, crane one is waiting for crane two to finish.

SC1 and SC2 make sure that only one crane is being worked at a time. These values are 52.9% and 63.4% correspondingly of the time these gates are open. It would seem that these values should be approximately 50% apiece; however, when the two cranes are both in a soak tank, both gates may be open. As soon as a crane is finished soaking, it instantly closes the other crane's gate, thus preventing simultaneous movement.

C2, ACID, P2, and SO2 prevent two cranes using the same soak at the same time. The gate C2 controls the caustic tank and is open 89% of the time. The gate that controls the acid tank is open (ACID) 70.8% of the time. P2, which controls the phosphate tank, is open an average of 91.6% of the time, and SC1, which controls the soap tank, is open 87.9% of the time.

From the amount of time the gates are open, it is obvious that a bottleneck occurs at the acid tank with that particular gate being open only 70.8% of the time. This is because of the high service time associated with the acid tank.

Two Crane One Operator Final Analysis

Trip output for the Two Crane One Operator System was considerably higher at an average of 779.3 trips for a 30 shift period than the Present System Model at an average of 439.6 trips. This was because of the extra transport in the new model. The output was not doubled because of factors such as crane interference and waiting times.

The tank times in the Two Crane One Operator System were greater than that of the Present Model. However, there are two items in the two crane system which account for the higher output of the two crane system. The tank time of crane one always lags just behind that of crane two. This is because crane two has to wait until crane one is finished so both cranes can move across the system to pick up another trip. The same logic as above follows for the total time in the system.

The average number of breakdowns of 5.2 for crane one and 6.1 for crane two fall in the range of breakdowns for the 95% confidence interval for the Present System Model of 0.15 and 9.85 breakdowns.

The ton output is correspondingly higher with the new model to the increased number of trips.

Two Crane Two Operator Model

The Two Crane and Two Operator Model was run for 360 hours or 30 shifts, as the previous two models. Output for the 10 runs are located in Appendix G.

Two Crane Two Operator Output

Table IX represents a summary of the output for the Two Crane Two Operator System. Trip output averaged at 676.9 trips for a 30 shift period, with a high of 689 and a low of 664 trips. The corresponding output per shift ranged between 22.1 and 22.9 trips per shift, with an average of 22.6 trips. Average time in the tanks ranged between 0.87 and 0.91 hours, with an average of 0.89 hours. Corresponding total times had a high of 1.06 hours and a low of 1.03 hours. Number of breakdowns for crane one ranged between 2 and 22, with an average of 7.7. The number of breakdowns for crane two had a low of 2, a high of 9 and an average of 4.9 breakdowns. Ton output had a low of 884 and a high of 951 tons, with an average of 917.2 tons.

Two Crane Two Operator Confidence Intervals

To further investigate the range of the values for the Two Crane Two Operator Model, a 95% confidence interval was calculated as in the previous two models.

Figure 23 represents the confidence interval for trip output of this model. There is a 95% confidence that for a 30 shift period the interval of 658.1 and 695.7 encompasses the true mean for the number of trips.

The confidence interval that represents tank time in the system is pictured in Figure 24. It can be said that there is a 95% confidence that the interval of 0.861 and 0.92 bounds the true mean of time in the tanks.

TABLE IX

OUTPUT FOR TWO CRANE TWO OPERATOR MODEL

Run	1	2	3	4	5	6	7	8	9	10	Avg.
Trip Output	667	678	664	686	674	670	689	672	684	685	676.9
Output/Shift	22.2	22.6	22.1	22.9	22.5	22.3	23	22.4	22.8	22.8	22.6
Tank Time	.91	.89	.89	.87	.89	.90	.87	.902	.88	.88	.89
Total Time	1.06	1.03	1.03	1.03	1.04	1.04	1.02	1.05	1.03	1.03	1.036
Number of Breakdowns System 1	12	5	22	5	8	9	2	9	3	2	7.7
Number of Breakdowns System 2	9	4	4	6	4	2	4	7	4	5	4.9
Ton Output	894	900	919	948	898	884	903	951	924	951	917.2

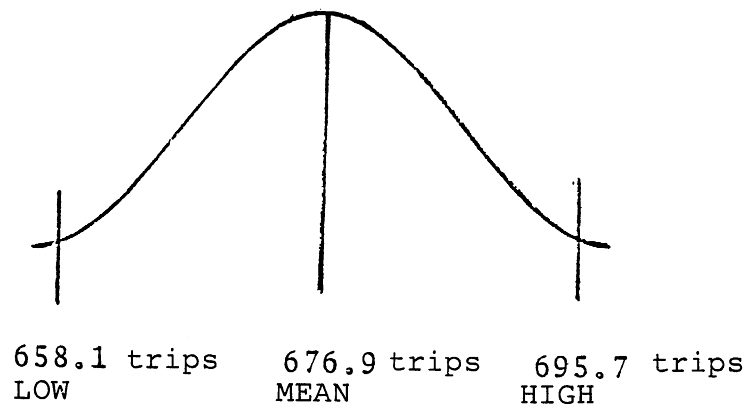


Figure 23. Confidence Interval of Trip Output for Two Crane Two Operator Model

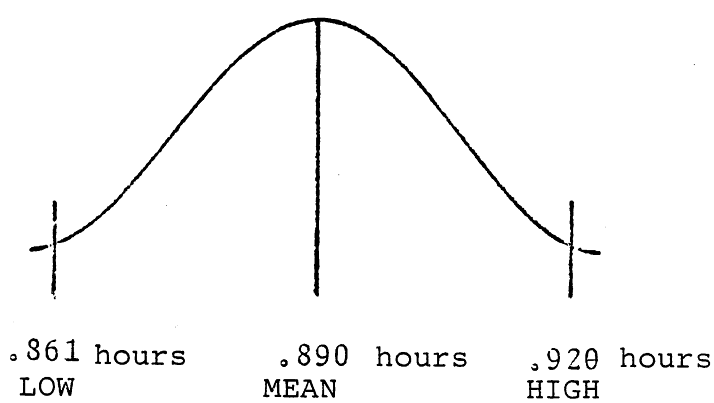


Figure 24. Confidence Interval of Tank Time for Two Crane Two Operator Model

For the total time in the system (Figure 25), it can be stated that there is a 95% confidence level that the interval of 1.011 and 1.061 includes the true mean of total time in the system.

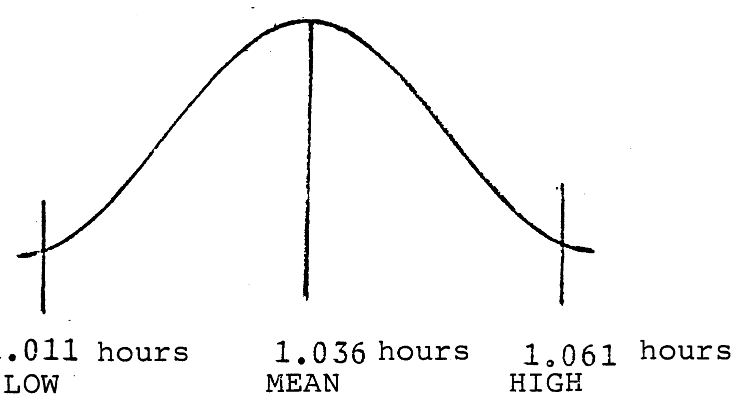


Figure 25. Confidence Interval of Total Time for Two Crane Two Operator Model

Figure 26 represents the confidence interval for the number of breakdowns for crane one. This 95% confidence level states the interval of 0 and 20.6 encases the true mean for breakdowns.

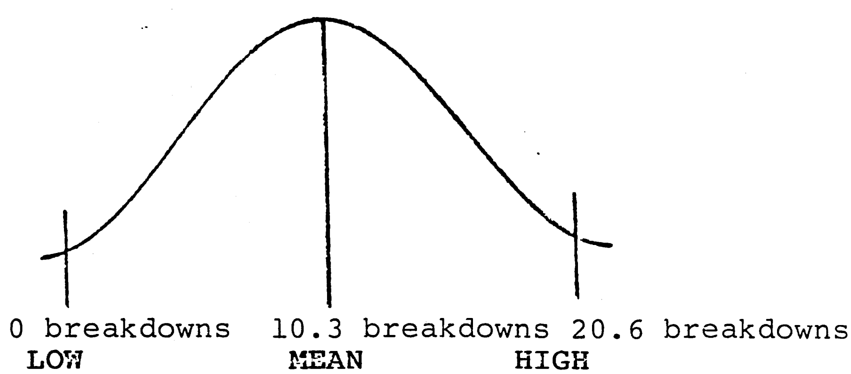


Figure 26. Confidence Interval of Breakdowns for Crane One of Two Crane Two Operator Model

The confidence interval that represents the number of breakdowns for crane two is represented by Figure 27. There is a 95% confidence level that the interval of 0.67 and 9.1 includes the true mean for breakdowns.

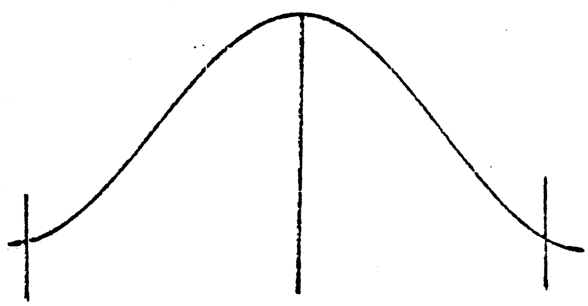


Figure 27. Confidence Interval of Breakdowns for Crane Two of Two Crane One Operator Model

Figure 28 represents the confidence interval for ton output. It can be stated that there is a 95% confidence that the interval of 862.77 and 971.62 encases the true mean for the number of tons in a 30 shift period.

<u>Resource Analysis of Two Crane Two Operator Model</u>

Table X represents the percentage of time the resources WC1 and WC2 were not in use. WC1 represents the resource used in waiting for crane two to pick up a trip. WC2 represents the resource used in waiting for crane two to receive a trip from crane one.

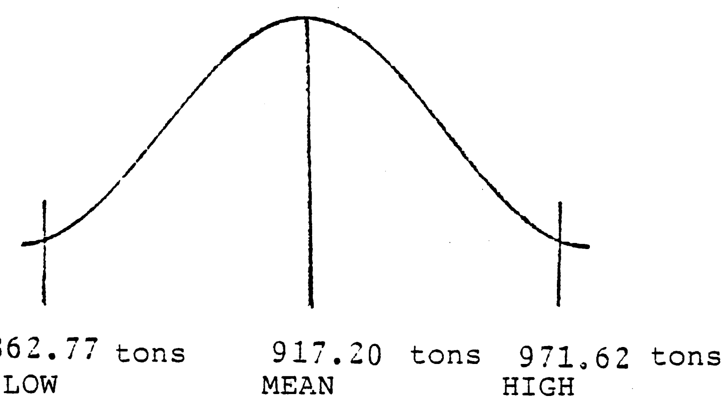


Figure 28. Confidence Interval of Ton Output for Two Crane Two Operator Model

WC1 is available 83.5% of the time, which means crane one hardly ever waits for crane two. WC2 is available 29% of the time, which means crane two waits for crane one 71% of the time. This is caused by the imbalance of the tanks at the "pinning off" area. To remedy this type of imbalance the pinning off should be moved over to allow less time for the crane one system and more time for the crane two system. However, this cannot be accomplished. The next tank that can be utilized as a pinning off area is the acid tank. Pinning off cannot be done here because of safety reasons and backtracking problems.

TABLE X

RESOURCE OUTPUT OF TWO CRANE TWO OPERATOR MODEL

Resource	1	2	3	4	5	6	7	8	9	10	Avg.
WC1	.8264	.8315	.8447	.8395	.8374	.8346	.8357	.8272	.8347	.8356	.835
WC2	.2887	.2864	.3107	.2848	.2944	.2952	.2837	.2848	.2828	.2856	.290

Two Crane Two Operator Final Analysis

Trip output was higher with 676.9 trips than the Present System Model with an average of 439.6 trips for a 30 shift period. However, because of the imbalance of the system, the trip output was lower than that of the Two Crane One Operator Model with an average of 779.3 trips for a 30 shift period.

The tank time in the system was slightly greater than that of the original system, with an average of 0.89 hours versus 0.82 hours. This is due to the "pinning off" function in the hot water tank. Tank time of the Two Crane One Operator System was approximately equal to that of the Two Crane Two Operator System.

The number of breakdowns for both cranes fall within the range of the other two systems with values of 7.7 and 4.9, respectively.

The ton output was lower than the Two Crane One Operator System, due to the smaller number of trips for 30 shifts at 578.96 tons.

CHAPTER VII

TANK SYSTEM ANALYSIS THROUGH CAN-Q

CAN-Q Input

Can-Q is a computer program that utilizes Queueing Theory and Markov Chains to analyze systems. The program uses mean service and travel times as opposed to distributions used in simulation. The following chapter contains CAN-Q input and output for the tank system. All input is simply the mean of times taken for the input used in the simulation. Each tank is divided into a station, a mean processing time and the number of servers is input for each station. Average dipping times plus soaking time (if soaking is required) is used as input for each station. Table XI represents the final input for CAN-Q. A routing for each product type is also required for CAN-Q. In the tank simulation, three different product routings are required. These products are normal lube, phosphate, and trick. Table XII represents the routing for the lube operation, Table XIII represents the routing for the phosphate operation, and Table XIV represents the routing for the trick operation.

Another type of input required for CAN-Q is a transport time between stations. Only one transport time is allowed

TABLE XI

CAN-Q INPUT

Station	Processing Time	Number of Servers
1 Holding	6.71 minutes	1
2 Caustic	6.68 minutes	1
3 Cold Water I	0.714 minutes	1
4 Acid	12.768 minutes	1
5 Hot Water	0.72 minutes	1
6 Phosphate	6.74 minutes	1
7 Cold Water II	0.714 minutes	1
8 Neutralizer	1.908 minutes	1
9 Soap	6.668 minutes	1
10 Dry	2.3 minutes	1
Crane Move Time	0.184 minutes	2
Number of Cranes in System	2	

TABLE XII

ROUTING FOR THE LUBE OPERATION

Operation Number	Station
1	Holding
2	Caustic
3	Cold Water
4	Acid
5	Cold Water
6	Hot Water
7	Phosphate
8	Cold Water
9	Neutralizer
10	Soap
11	Dry

TABLE XIII

ROUTING FOR PHOSPHATE OPERATION

Operation Number	Station
1	Holding
2	Caustic
3	Cold Water
4	Acid
5	Cold Water
6	Hot Water
7	Phosphate
8	Cold Water II
9	Dry

TABLE XIV

ROUTING FOR TRICK OPERATION

Operation Number	Station
1	Holding
2	Caustic
3	Cold Water
4	Acid
5	Cold Water
6	Hot Water
7	Dry

in CAN-Q. This time for the tank system is the average time between stations, a value of 0.18 minutes.

The last type of input that must be made for CAN-Q is the number of items in the system. This determines how many items can be in the production at one time. The number of items must be two or greater.

CAN-Q Output Analysis

Output for CAN-Q (Appendix H) contains a routing for each product type, input data summary, system performance measures, summary for each station, and sensitivity information. However, the only information that is valuable in determining the final analysis of the tank system is located in the summary of each station and the system performance measures, the routings and input data section are mainly used for data input verification. The sensitivity information is useful if product types or service times can be changed.

System Performance Measures

The System Performance Measures section contains the most valuable information on the system for the tanks.

Table XV contains the final information from the System Performance Measures Section. Production rate is the first value given. For two items (items represent cranes) in the system, the production rate is 2.192 items per hour. Production rates by product type are also given; these are

TABLE XV

SYSTEM PERFORMANCE SUMMARY

SYSTEM PERFORMANCE MEASURES

PRODUCTION RATE = 2.192 ITEMS PER HOUR

PRODUCTION RATES BY PRODUCT TYPE

	NUMBER	VALUE
LUBE	1.951	1.951
PHO	.088	.088
TRI	.153	.153

TOTAL VALUE = 2.192

AVERAGE TIME IN SYSTEM = 54.74 MINUTES

PROCESSING	45.14
TRAVELING	1.92
WAITING	7.69

FUNCTIONS OF N, NUMBER OF ITEMS IN THE SYSTEM

N	PRODUCTION RATE	AVERAGE TIME IN THE SYSTEM
1	1.275	47.056
2	2.192	54.744
3	2.854	63.063
4	3.332	72.029
5	3.674	81.649
6	3.917	91.717
7	4.085	102.804
.	.	.
.	.	.
.	.	.
INF	4.412	INF

THE BOTTLENECK STATION IS 4

simply the fraction of the product type in the system multiplied by the overall production rate. An average time in the system is then given. This value is 54.74 minutes. This time is then broken down into actual processing time at 45.14 minutes, traveling time at 1.92 minutes, and waiting time at 7.69 minutes. Finally a production rate and an average time in the system is given for different numbers of items in the system. For one item in the system, the production rate is 1.275 items per hour with an average time in the system of 47.056 minutes.

The only way to compare the one and two crane systems is through the production rate and average time in the system. This is because CAN-Q will not accept a number in the system less than two. However, a good picture of the increase in the system by adding one crane is given through this information. There is an increase in production of almost one item per hour by adding an extra crane. Average time in the system increases by 7.7 minutes because of waiting for processing, but there are two items being processed, increasing the output of the system.

Finally, information is given on where the bottleneck is located in the system. The bottleneck in the tanks is located at the acid tank, station four.

Station Summary

The Station Summary contains information dealing with each particular station. The most useful summary is contained within the station containing the bottleneck of the system. Station four is the bottleneck located in the tank system.

Station four is the station that is used for the dipping and soaking of the bales in acid (Table XVI). Server utilization for this particular station is approximately 49.7%. The average number of items in process and waiting for this station is 1.281, the average number of items in process is 0.497, and the average number of items waiting is 0.784. Average time spent per operation at this station is 35.061 minutes. Processing time takes 13.6 minutes of this time, while waiting takes 21.461 minutes. The fraction of time there are zero items at the station is 0.5031. The fraction of the time there is one item at the station is 0.4969.

TABLE XVI

STATION SUMMARY FOR ACID TANK

SUMMARY FOR STATION NUMBER 4 : ACID

NUMBER OF SERVERS	SERVER UTILIZATION	AVE. NO. OF BUSY SERVERS
1	.497	.497

STEADY STATE AVERAGE NUMBER OF :

ITEMS WAITING	1.281
ITEMS IN PROCESS	.497
ITEMS WAITING	.784

AVERAGE TIME SPENT AT THIS STATION	PER OPERATION	PER ITEM
TOTAL TIME (MINUTES)	35.061	35.061
PROCESSING	13.600	13.600
WAITING	21.461	21.461

FRACTION OF TIME	X ITEMS AT STATION	X ITEMS EXCEEDED
X = 0	.5031	.4969
X = 1	.4969	.0000
X = 2	.1436	#####

CHAPTER VIII

COMPARISON OF CAN-Q AND SIMULATION

This chapter compares the CAN-Q output with the simulation output. This is accomplished through the use of confidence intervals. An economic analysis is also done on the outputs of both the SLAM model and CAN-Q to determine if the addition of the cranes is economically feasible.

Original System Simulation and CAN-Q

In comparing the Present System Simulation with CAN-Q, only two numbers from the output of CAN-Q will be compared to the simulation output: time spent in the system, and output. Comparisons will be made through confidence intervals calculated from the simulation output.

The production rate calculated through CAN-Q is 1.275 items per hour. Multiplying this number by 360 an output of 459 items is obtained. Figure 29 shows where this number lies compared with the simulation's 95% confidence interval. The number is slightly high, probably because breakdowns cannot be modeled into the system. Taking an average output per day shows how close the production rate for the simulation and CAN-Q really are. CAN-Q's output per day is 15.3 trips, while the average number of trips per day for the simulation model is 14.65 trips.

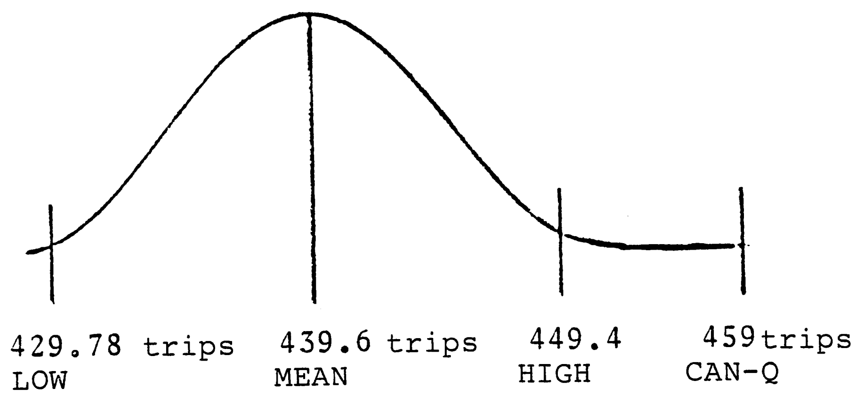


Figure 29. Confidence Interval of the Present System Output and CAN-Q Output

Average time in the tank is 47.056 minutes, or 0.784 hours. Figure 30 shows where this value lies when compared with the simulation's 95% confidence interval for tank time in the Present System Model. This number is slightly lower because of the inability of CAN-Q to handle breakdowns.

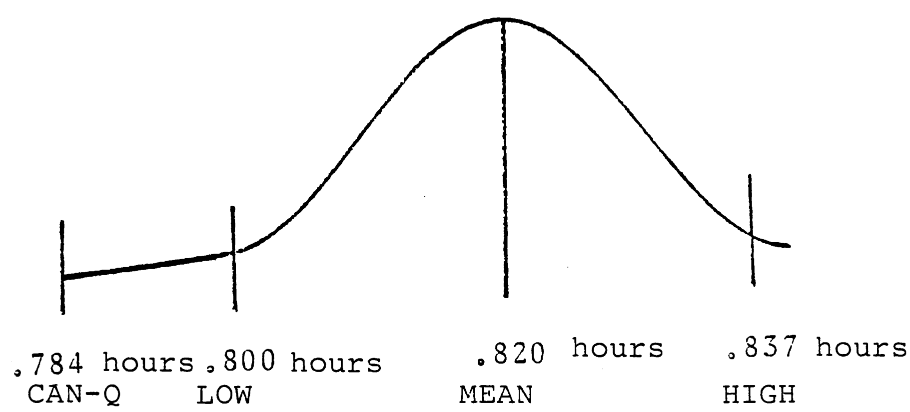


Figure 30. Confidence Interval of the Present System Tank Time and CAN-Q Tank Time

Two Crane One Operator Simulation and CAN-Q

Output from the Two Crane One Operator System Simulation is extremely close to that of CAN-Q. Figure 31 represents the 95% confidence interval of the production for 360 hours. The production for CAN-Q of 789.12 trips for 360 hours lies almost midway between the mean of 779.3 trips and the upper limit value of 798 trips with respect to the simulation's output. The CAN-Q output of the production is slightly higher because of the inability to model breakdowns. Another reason the output might be slightly higher is because of the lack of ability for CAN-Q to model crane interference. This is especially true at the drying portion of the tanks. CAN-Q does not allow one crane to wait until the other crane is finished so they both may move back to the beginning of the tanks.

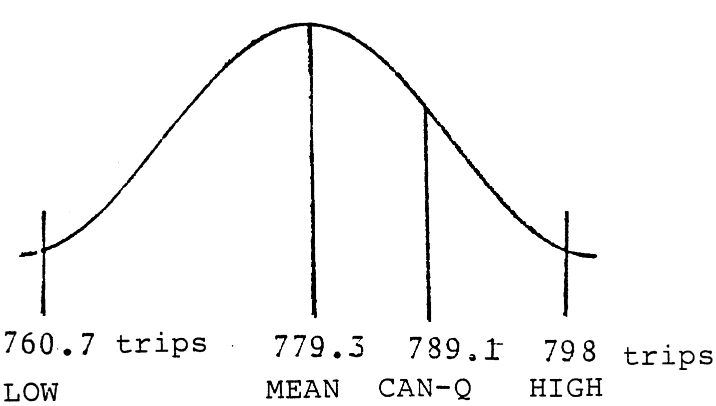


Figure 31. Confidence Interval of Two Crane One Operator Output and CAN-Q Output

The average time of the system, however, is also slightly higher than the average tank time for the Two Crane One Operator Model (Figure 32). This is possibly due to random variation in the simulation model.

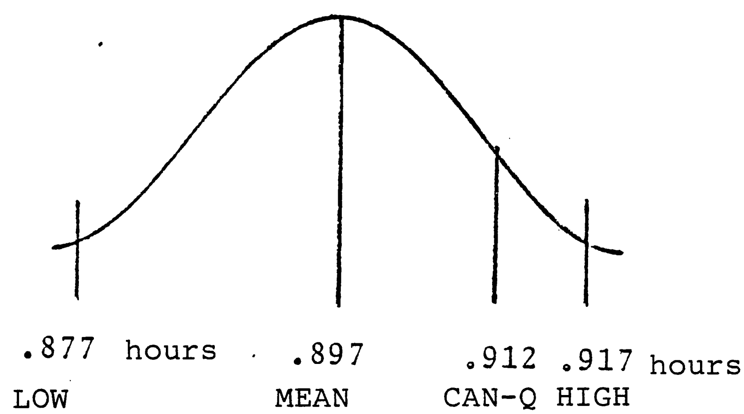


Figure 32. Confidence Interval of Two Crane One Operator Tank Time and CAN-Q Tank Time

Two Crane Two Operator Simulation and CAN-Q

The difference between this simulation and CAN-Q is greater than the difference found for the other models. Figure 33 depicts where the value of production output falls for 360 hours calculated through CAN-Q with respect to a confidence interval derived from the Two Crane Two Operator Simulation Model. CAN-Q's value of 789.12 trips lies well above the confidence interval upper value of 695.7 trips.

This is due to the inefficiency of the Two Crane Two Operator Model to utilize the second crane.

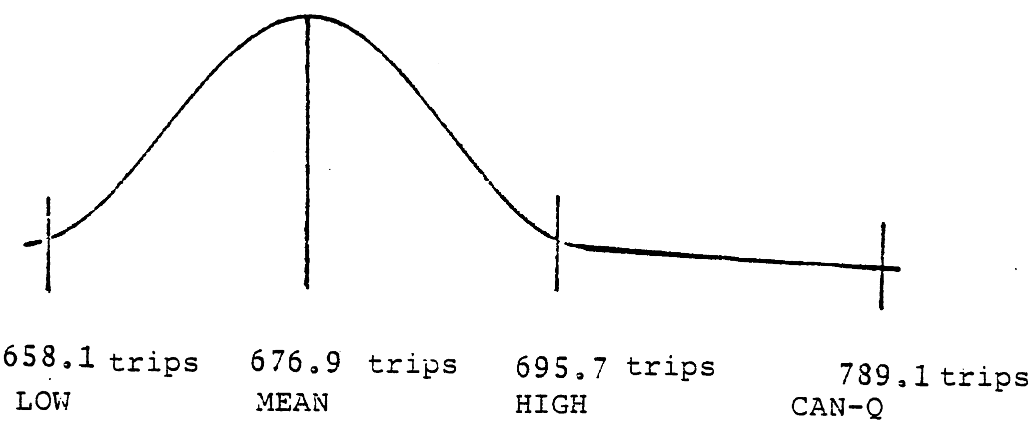


Figure 33. Confidence Interval of Two Crane Two Operator System Output and CAN-Q Output

Average time in the system of CAN-Q, however, does fall within this simulation's 95% confidence interval of tank time (Figure 34). This value of 0.912 hours is slightly greater than the mean value given through the simulation of 0.89 hours. This is also probably due to random variation in the simulation model.

Economic Analysis of Outputs by

Simulation and CAN-Q

A net present worth was calculated for a one, three, and five year period using the averages for tonnage generated by the simulation models, and average output per trip from data collection.

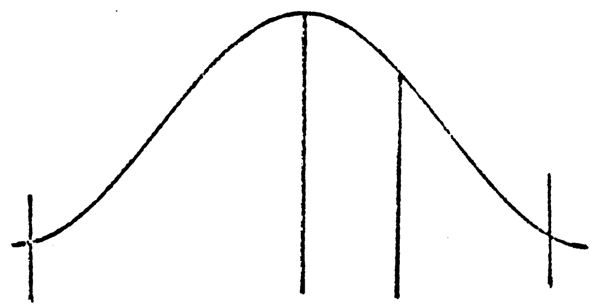


Figure 34. Confidence Interval of Two Crane Two Operator System Tank Time and CAN-Q Tank Time

In the economic analysis, each net present worth represents the added income above the original model. This means that the total tonnage for each proposed system was adjusted by subtracting the present system's tonnage from them. Management stated that the Minimum Attractive Rate of Return for the company is 12%, and the profit after overhead generated per ton is approximately $100.00. Table XVII represents the final tabulations for the Two Crane One Operator Model and the Two Crane Two Operator Model.

The Two Crane One Operator Model had no personnel cost. This is because the same operator operates the added crane.

TABLE XVII

ECONOMIC ANALYSIS OF TANK SYSTEM

System	Personnel	Equipment	Income Generated Above Original Model*	NPW Above Original System		
				1 year	3 year	5 year
Two Cranes One Operator	-	25,000	1,126,700	981,030	2,681,108	4,036,528
Full System	-	50,000	2,253,400	1,962,061	5,362,216	8,073,056
Two Cranes Two Operators	101,400	25,000	695,760	596,244	1,646,076	2,483,076
Full System	202,800	50,000	1,391,520	1,192,488	3,292,152	4,966,152
CAN-Q One Operator	-	25,000	1,071,059	931,349	2,547,470	3,835,954
Full System	-	50,000	2,142,117	1,862,697	5,094,940	7,671,907
CAN-Q Two Operators	101,400	25,000	969,659	840,809	2,303,927	3,470,427
Full System	202,800	50,000	1,939,318	1,681,618	4,607,854	6,940,854

*Tonnage/year * 100.00 - Operator Cost

12% MARR

Equipment cost per crane after installation is approximately $25,000.00. The total income generated per year is $1,126,700 for adding a crane to one half of the system and $2,253,400 for adding cranes to both halves of the system (the simulation only simulated one side of the tanks). Net present worth for one half of the system was $981,030, $2,681,108, and $4,036,528 for a one, three and five year period, respectively. The net present worth for a one, three and five year period for the full system was $1,962,061, $5,362,216, and $8,073,056, respectively.

The Two Crane Two Operator Model incurred the cost of personnel. This amounted to $101,400 as estimated by management. This includes operators for the day and night shift for both the weekend and the weekday crew. Equipment cost is the same as the previous system at $25,000 per crane after installation. Income generated per year from the addition of the cranes was $797,100 for half the system, and $1,594,200 for the full system. Net present worth for half the system was $596,244, $1,646,076, and $2,483,076 for a one, three and five year period, respectively. The full system generated a net present worth of $1,192,488, $3,292,152, and $4,966,152 for a one, three and five year system, respectively.

CAN-Q, utilizing an average tone output of 1.337 tons per trip and costs incurred for equipment, yields a present value of $931,349, $2,547,470, and $3,835,954 for one, three and five years for half of the system. The full system yields present values of $1,862,697, $5,094,940, and $7,671,097 for one, three and five years, respectively.

The CAN-Q net present value for two operators is $840,809, $2,303,927, $3,470,427 for one, three and five years. These values are for one half of the system. The full system present value for two operators is $1,681,618, $4,607,854, and $6,940,854 for one, three and five years, respectively.

Clearly, the Two Crane One Operator system is best in an economical sense for both the simulation and CAN-Q. However, CAN-Q cannot distinguish between the two types of models run by the simulation. All values from both outputs of CAN-Q and simulation are very close, though, and the way in which CAN-Q operates is closer to the Two Crane One Operator Model than the Two Crane Two Operator Model.

CHAPTER IX

CONCLUSIONS

In making management decisions, both CAN-Q and simulation can be very valuable. In this particular situation many trade-offs are involved in using the two different techniques.

Simulation requires extensive system analysis and data collection while CAN-Q requires no modeling and very little data collection. This particular simulation project had a data collection period and system analysis of approximately three months. Another two months was required to build and verify these models. CAN-Q would take approximately two weeks of data collection and no distribution testing, plus no modeling.

Simulation requires expertise while CAN-Q does not. This means that management can utilize CAN-Q without an expert in modeling. For simulation, management will either hire someone or have someone else within the company with the expertise run the simulation for them.

Simulation requires a special software package and in most cases, at least a mini-computer to handle this type of software. CAN-Q is approximately 500 lines in length and can fit on a micro-computer.

CAN-Q only gives means, and not ranges. Simulation does give means and ranges for the poorest and best performance of a particular system. In this particular problem, though, system variability was not very high.

The most important factor in the difference between CAN-Q and simulation is accuracy as compared to the real system. Both CAN-Q and simulation showed the proposed addition of the cranes as extremely attractive. CAN-Q did not show, as the simulation did, the optimum arrangement of the cranes and how many operators were needed. The simulation showed clearly that the optimum system was a two crane one operator type of setup, while CAN-Q basically showed only that adding an extra crane would be profitable. CAN-Q also could not analyze the breakdowns of the system. In this case, there was not a large difference in the numbers; however, in a system where frequent breakdowns could occur, CAN-Q may become more inaccurate.

CAN-Q may also be a valuable tool in verifying and validating a simulation. In this particular case, values of simulation and CAN-Q were comparable. Even if values in CAN-Q deviate from the values of simulation, and these deviations can be accounted for, CAN-Q can be a quick way to see if a modeler is on the right track with a simulation model.

The bottom line between simulation and CAN-Q is accuracy versus cost. In this case, both types of analysis revealed it was profitable to add another crane. However, simulation told exactly how to situate the crane while CAN-Q did not. Simulation also enabled the modeling of breakdowns while CAN-Q could not. CAN-Q, though, takes much less time to develop. In this particular case it would take five to seven months to develop the simulation, compared to two weeks for CAN-Q.

Finally, both the simulation and CAN-Q showed it was extremely profitable to add the cranes. Even though CAN-Q was very close to the simulation's findings, the simulation showed it was most profitable to add an extra crane with one operator.

There are trade-offs in using simulation and CAN-Q. Further research should be done on different types of systems to see if CAN-Q or simulation is more appropriate in different situations.

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APPENDIXES

APPENDIX A

DATA COLLECTED AND CORRESPONDING HISTOGRAMS

CAUSTIC DIPPING

ORDERED DATA

.008	.009	.009	.009	.009
.009	.010	.010	.012	.012
.012	.012	.012	.012	.012
.012	.013	.013	.013	.013
.013	.013	.013	.014	.014
.014	.014	.014	.015	.015
.016	.017	.017	.017	.017
.017	.017	.017	.017	.018
.018	.019	.019	.023	.023

```
         *****   HISTOGRAM   *****
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    11                 *
    10                 *
     9                 *
     8             *   *       *
     7             *   *       *
     6     *       *   *       *
     5     *       *   *       *
     4     *       *   *       *   *
     3     *       *   *   *   *   *
     2     *   *   *   *   *   *   *           *
     1     *   *   *   *   *   *   *           *
      ----------------------------------------
NUMBER     6   2   8  12   3   8   4   0   0   2
CLASS

START    .008  STOP    .024 SIZE OF INTERVAL            .0016
CALCULATED MEAN=      .01404 CALCULATED VARIANCE=      .00001
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****

HYPOTHESIS STATEMENT

NULL HYPOTHESIS= POPULATION IS NORMAL WITH TRUE MEAN= .0140
ALTERNATIVE HYPOTHESIS= POPULATION IS NOT NORMAL WITH TRUE MEAN= .0140

****
NUMBER OF OBSERVATIONS= 45

KOLMOGOROV - SMIRNOV TEST

CELLS	RANGE FROM	TO	OBSERVED	OBSERVED FREQUENCY	CUMULATIVE OBSERVED FREQUENCY	THEORETICAL FREQUENCY	CUMULATIVE THEORETICAL FREQUENCY	KOLMOGOROV - SMIRNOV STATISTIC
1	-999.99902	.00950	6.00000	.13333	.13333	.04423	.04423	.08910
2	.00950	.01100	2.00000	.04444	.17778	.15120	.19543	.01765
3	.01100	.01250	8.00000	.17778	.35556	.13624	.33168	.02388
4	.01250	.01400	12.00000	.26667	.62222	.16333	.49500	.12722
5	.01400	.01550	2.00000	.04444	.66667	.16418	.65918	.00748
6	.01550	.01700	9.00000	.20000	.86667	.13839	.79758	.06909
7	.01700	.01850	2.00000	.04444	.91111	.09782	.89540	.01571
8	.01850	.02000	2.00000	.04444	.95556	.05798	.95338	.00218
9	.02000	.02150	.00000	.00000	.95556	.02881	.98219	.02664
10	.02150	.02300	2.00000	.04444	1.00000	.01201	.99420	.00580

THE KOLMOGOROV - SMIRNOV STATISTIC = .12722

DEGREES OF FREEDOM= 10
MU= .014044449 SIGMA 2= .000012589

COLD WATER DIPPING

ORDERED DATA

.006	.006	.006	.007	.008
.008	.009	.009	.009	.009
.009	.009	.009	.010	.010
.010	.010	.010	.011	.011
.012	.012	.012	.012	.012
.012	.012	.013	.013	.014
.014	.014	.014	.014	.014
.014	.015	.015	.015	.015
.016	.017	.017	.020	.021

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  10                           *
   9         *         *       *
   8         *         *       *
   7         *         *       *
   6         *         *       *
   5         *    *    *       *
   4    *    *    *    *       *
   3    *    *    *    *       *    *
   2    *    *    *    *    *  *    *
   1    *    *    *    *    *  *    *         *    *
   ----------------------------------------------------
NUMBER  4    9    5    9    2  11   3    0    1    1

CLASS

START     .006   STOP     .022 SIZE OF INTERVAL            .0016
CALCULATED MEAN=      .01189 CALCULATED VARIANCE=      .00001
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****

HYPOTHESIS STATEMENT

NULL HYPOTHESIS= POPULATION IS NORMAL WITH TRUE MEAN= .0119
ALTERNATIVE HYPOTHESIS= POPULATION IS NOT NORMAL WITH TRUE MEAN= .0119

****
NUMBER OF OBSERVATIONS= 45

KOLMOGOROV - SMIRNOV TEST

CELLS	RANGE FROM	TO	OBSERVED	OBSERVED FREQUENCY	CUMULATIVE OBSERVED FREQUENCY	THEORETICAL FREQUENCY	CUMULATIVE THEORETICAL FREQUENCY	KOLMOGOROV - SMIRNOV STATISTIC
1	-999.99902	.00750	4.00000	.08889	.08889	.04433	.04433	.04456
2	.00750	.00900	9.00000	.20000	.28889	.15748	.20181	.08708
3	.00900	.01050	5.00000	.11111	.40000	.14221	.34402	.05598
4	.01050	.01200	9.00000	.20000	.60000	.16880	.51281	.03719
5	.01200	.01350	2.00000	.04444	.64444	.16650	.67931	.03487
6	.01350	.01500	11.00000	.24444	.88889	.13648	.81579	.07310
7	.01500	.01650	1.00000	.02222	.91111	.09296	.90875	.00236
8	.01650	.01800	2.00000	.04444	.95556	.05262	.96136	.00581
9	.01800	.01950	.00000	.00000	.95556	.02475	.98611	.03055
10	.01950	.02100	2.00000	.04444	1.00000	.00967	.99578	.00422

THE KOLMOGOROV - SMIRNOV STATISTIC = .08719

DEGREES OF FREEDOM= 10
MU= .011888888 SIGMA 2= .000011965

ACID DIPPING

ORDERED DATA

.008	.008	.008	.009	.009
.009	.011	.011	.011	.011
.012	.012	.012	.012	.012
.012	.013	.013	.013	.013
.013	.014	.014	.014	.014
.014	.014	.015	.015	.016
.016	.016	.016	.016	.016
.017	.017	.017	.017	.017
.017	.018	.019	.022	.023

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    10                 *
     9                 *
     8                 *    *
     7                 *    *
     6     *       *   *    *    *
     5     *       *   *    *    *
     4     *   *   *   *    *    *
     3     *   *   *   *    *    *
     2     *   *   *   *    *    *    *
     1     *   *   *   *    *    *    *         *    *
       ------------------------------------------------
NUMBER     6   4   6   11   8    6    2    0    1    1
CLASS

 START    .008  STOP    .024 SIZE OF INTERVAL          .0016
 CALCULATED MEAN=     .01391 CALCULATED VARIANCE=     .00001
WOULD YOU LIKE TO CHANGE THE THE NUMBER OF CELLS ?
```

****

HYPOTHESIS STATEMENT

NULL HYPOTHESIS= POPULATION IS NORMAL WITH TRUE MEAN= .0139
ALTERNATIVE HYPOTHESIS= POPULATION IS NOT NORMAL WITH TRUE MEAN= .0139

****
NUMBER OF OBSERVATIONS= 45

KOLMOGOROV - SMIRNOV TEST

CELLS	RANGE FROM	TO	OBSERVED	OBSERVED FREQUENCY	CUMULATIVE OBSERVED FREQUENCY	THEORETICAL FREQUENCY	CUMULATIVE THEORETICAL FREQUENCY	KOLMOGOROV - SMIRNOV STATISTIC
1	-999.99902	.00950	6.00000	.13333	.13333	.04181	.04181	.09152
2	.00950	.01100	4.00000	.08889	.22222	.15529	.19710	.02512
3	.01100	.01250	6.00000	.13333	.35556	.14270	.33980	.01575
4	.01250	.01400	11.00000	.24444	.60000	.17058	.51038	.08962
5	.01400	.01550	2.00000	.04444	.64444	.16867	.67905	.03460
6	.01550	.01700	12.00000	.26667	.91111	.13797	.81702	.09409
7	.01700	.01850	1.00000	.02222	.93333	.09336	.91038	.02296
8	.01850	.02000	1.00000	.02222	.95556	.05226	.96263	.00708
9	.02000	.02150	.00000	.00000	.95556	.02419	.98683	.03127
10	.02150	.02300	2.00000	.04444	1.00000	.00927	.99609	.00391

THE KOLMOGOROV - SMIRNOV STATISTIC = .09409

DEGREES OF FREEDOM= 10
MU= .013911108 SIGMA 2= .000011674

ACID SOAK

ORDERED DATA

.117	.117	.117	.117	.150
.150	.150	.167	.167	.167
.167	.167	.183	.183	.183
.183	.200	.200	.200	.200
.200	.200	.200	.200	.200
.200	.200	.200	.217	.217
.217	.217	.233	.233	.233
.233	.233	.250	.250	.250
.250	.250	.250	.250	.283

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    6                       *                 *
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    4     *           *     *     *     *     *     *
    3     *     *     *     *     *     *     *     *
    2     *     *     *     *     *     *     *     *
    1     *     *     *     *     *     *     *     *           *
     ------------------------------------------------------------
NUMBER    4     3     5     4    12     4     5     7     0     1
CLASS

START    .117  STOP    .284 SIZE OF INTERVAL          .0167
CALCULATED MEAN=     .19891 CALCULATED VARIANCE=     .00165
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****

HYPOTHESIS STATEMENT

NULL HYPOTHESIS= POPULATION IS NORMAL WITH TRUE MEAN= .1989
ALTERNATIVE HYPOTHESIS= POPULATION IS NOT NORMAL WITH TRUE MEAN= .1989

****
NUMBER OF OBSERVATIONS= 45

KOLMOGOROV - SMIRNOV TEST

CELLS	RANGE FROM	TO	OBSERVED	OBSERVED FREQUENCY	CUMULATIVE OBSERVED FREQUENCY	THEORETICAL FREQUENCY	CUMULATIVE THEORETICAL FREQUENCY	KOLMOGOROV - SMIRNOV STATISTIC
1	-999.99902	.13360	4.00000	.08889	.08889	.02187	.02187	.06702
2	.13360	.15020	3.00000	.06667	.15556	.09335	.11522	.04034
3	.15020	.16680	.00000	.00000	.15556	.09938	.21460	.05905
4	.16680	.18340	9.00000	.20000	.35556	.13668	.35128	.00428
5	.18340	.20000	12.00000	.26667	.62222	.15942	.51070	.11153
6	.20000	.21660	.00000	.00000	.62222	.15770	.66840	.04617
7	.21660	.23320	9.00000	.20000	.82222	.13232	.80071	.02151
8	.23320	.24980	.00000	.00000	.82222	.09416	.89487	.07265
9	.24980	.26640	7.00000	.15556	.97778	.05683	.95170	.02608
10	.26640	.28300	1.00000	.02222	1.00000	.02709	.98078	.01922

DEGREES OF FREEDOM= 10
MU= .198911071 SIGMA 2= .001649856

THE KOLMOGOROV - SMIRNOV STATISTIC = .11153

HOT WATER DIPPING

ORDERED DATA

.006	.006	.006	.006	.008
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.009	.009	.010	.010	.010
.010	.010	.011	.011	.012
.012	.012	.012	.012	.012
.012	.013	.013	.014	.014
.014	.014	.014	.014	.015
.015	.015	.015	.015	.016
.016	.016	.016	.019	.021

```
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      8       *           *     *
      7       *           *     *
      6       *           *     *
      5       *     *     *     *
      4  *    *     *     *     *    *
      3  *    *     *     *     *    *
      2  *    *     *     *  *  *    *
      1  *    *     *     *  *  *    *         *    *
       ------------------------------------------------
NUMBER    4    8    5    9    2   11    4    0    1    1
CLASS

START    .006  STOP    .022 SIZE OF INTERVAL          .0016
CALCULATED MEAN=     .01138 CALCULATED VARIANCE=     .00001
```

****

HYPOTHESIS STATEMENT

NULL HYPOTHESIS= POPULATION IS NORMAL WITH TRUE MEAN= .0120
ALTERNATIVE HYPOTHESIS= POPULATION IS NOT NORMAL WITH TRUE MEAN= .0120

****
NUMBER OF OBSERVATIONS= 45

KOLMOGOROV - SMIRNOV TEST

CELLS	RANGE FROM	RANGE TO	OBSERVED	OBSERVED FREQUENCY	CUMULATIVE OBSERVED FREQUENCY	THEORETICAL FREQUENCY	CUMULATIVE THEORETICAL FREQUENCY	KOLMOGOROV - SMIRNOV STATISTIC
1	-999.99902	.00750	4.00000	.08889	.08089	.04059	.04059	.04830
2	.00750	.00900	8.00000	.17778	.26667	.15191	.19250	.07417
3	.00900	.01050	5.00000	.11111	.37778	.14069	.33319	.04459
4	.01050	.01200	9.00000	.20000	.57778	.16940	.50259	.07519
5	.01200	.01350	2.00000	.04444	.62222	.16893	.67151	.04929
6	.01350	.01500	11.00000	.24444	.86667	.13952	.81103	.05564
7	.01500	.01650	4.00000	.08889	.95556	.09544	.90647	.04909
8	.01650	.01800	.00000	.00000	.95556	.05407	.96053	.00493
9	.01800	.01950	1.00000	.02222	.97778	.02537	.98590	.00812
10	.01950	.02100	1.00000	.02222	1.00000	.00986	.99576	.00424

DEGREES OF FREEDOM= 10
MU= .011977775 SIGMA 2= .000011749

THE KOLMOGOROV - SMIRNOV STATISTIC = .07519

PHOSPHATE DIPPING

ORDERED DATA

.007	.008	.008	.008	.010
.010	.011	.011	.011	.011
.011	.011	.012	.012	.012
.012	.012	.012	.013	.013
.013	.014	.014	.014	.014
.014	.014	.015	.015	.017
.017	.017	.017	.017	.017
.017	.017	.017	.017	.019
.020	.021	.022	.025	.033

```
        *****    HISTOGRAM    *****
 14          *
 13          *
 12          *
 11          *    *
 10          *    *    *
  9          *    *    *
  8          *    *    *
  7          *    *    *
  6          *    *    *
  5          *    *    *
  4     *    *    *    *
  3     *    *    *    *
  2     *    *    *    *    *    *
  1     *    *    *    *    *    *    *                   *
    ----------------------------------------------------------
NUMBER  4   14   11   10    2    2    1    0    0    1
CLASS

START    .007  STOP    .034 SIZE OF INTERVAL          .0027
CALCULATED MEAN=      .01449 CALCULATED VARIANCE=    .00002
```

****

HYPOTHESIS STATEMENT

NULL HYPOTHESIS= POPULATION IS NORMAL WITH TRUE MEAN= .0145
ALTERNATIVE HYPOTHESIS= POPULATION IS NOT NORMAL WITH TRUE MEAN= .0145

****
NUMBER OF OBSERVATIONS= 45

KOLMOGOROV - SMIRNOV TEST

CELLS	RANGE FROM	TO	OBSERVED	OBSERVED FREQUENCY	CUMULATIVE OBSERVED FREQUENCY	THEORETICAL FREQUENCY	CUMULATIVE THEORETICAL FREQUENCY	KOLMOGOROV - SMIRNOV STATISTIC
1	-979.99902	.00960	4.00000	.08889	.08889	.05877	.05877	.03012
2	.00960	.01220	14.00000	.31111	.40000	.25742	.31619	.08381
3	.01220	.01480	9.00000	.20000	.60000	.20974	.52592	.07408
4	.01480	.01740	12.00000	.26667	.86667	.20263	.72855	.13811
5	.01740	.02000	2.00000	.04444	.91111	.14676	.87531	.03580
6	.02000	.02260	2.00000	.04444	.95556	.07968	.95499	.00057
7	.02260	.02520	1.00000	.02222	.97778	.03242	.98741	.00963
8	.02520	.02780	.00000	.00000	.97778	.00989	.99730	.01952
9	.02780	.03040	.00000	.00000	.97778	.00226	.99956	.02178
10	.03040	.03300	1.00000	.02222	1.00000	.00039	.99995	.00005

THE KOLMOGOROV - SMIRNOV STATISTIC = .13811

DEGREES OF FREEDOM= 10
MU= .014488893 SIGMA 2= .000022892

NEUTRALIZER DIPPING

ORDERED DATA

.010	.010	.011	.011	.011
.011	.012	.012	.012	.012
.012	.014	.014	.014	.014
.014	.014	.014	.014	.014
.014	.015	.015	.016	.016
.016	.017	.017	.017	.017
.017	.019	.019	.019	.019
.020	.020	.020	.020	.020
.020	.020	.021	.025	.026

```
         *****    HISTOGRAM    *****
 12                   *
 11                   *        *
 10                   *        *
  9                   *        *
  8                   *        *
  7                   *        *
  6        *          *        *
  5        *    *     *     *  *
  4        *    *     *     *  *
  3        *    *     *  *  *  *
  2        *    *     *  *  *  *
  1        *    *     *  *  *  *  *     *  *
    ------------------------------------------
NUMBER     6    5    12  3  5  11 1  0  1  1
```

CLASS

START .010 STOP .027 SIZE OF INTERVAL .0017
CALCULATED MEAN= .01589 CALCULATED VARIANCE= .00001

****

HYPOTHESIS STATEMENT

NULL HYPOTHESIS= POPULATION IS NORMAL WITH TRUE MEAN= .0159
ALTERNATIVE HYPOTHESIS= POPULATION IS NOT NORMAL WITH TRUE MEAN= .0159

****
NUMBER OF OBSERVATIONS= 45

KOLMOGOROV - SMIRNOV TEST

CELLS	RANGE FROM	TO	OBSERVED	OBSERVED FREQUENCY	CUMULATIVE OBSERVED FREQUENCY	THEORETICAL FREQUENCY	CUMULATIVE THEORETICAL FREQUENCY	KOLMOGOROV - SMIRNOV STATISTIC
1	-999.99902	.01160	6.00000	.13333	.13333	.06310	.06310	.07024
2	.01160	.01320	5.00000	.11111	.24444	.17941	.24250	.00194
3	.01320	.01480	10.00000	.22222	.46667	.14617	.38868	.07799
4	.01480	.01640	5.00000	.11111	.57778	.16412	.55280	.02498
5	.01640	.01800	5.00000	.11111	.68889	.15544	.70823	.01935
6	.01800	.01960	4.00000	.08889	.77778	.12418	.83241	.05463
7	.01960	.02120	8.00000	.17778	.95556	.08368	.91609	.03947
8	.02120	.02280	.00000	.00000	.95556	.04756	.96365	.00810
9	.02280	.02440	.00000	.00000	.95556	.02200	.98646	.03090
10	.02440	.02600	2.00000	.04444	1.00000	.00922	.99568	.00432

THE KOLMOGOROV - SMIRNOV STATISTIC = .07799

DEGREES OF FREEDOM= 10
MU= .015888888 SIGMA 2= .000014828

SOAP DIPPING

ORDERED DATA

.007	.008	.009	.009	.009
.009	.011	.011	.012	.012
.012	.012	.012	.012	.012
.012	.012	.013	.013	.013
.013	.013	.013	.014	.014
.014	.014	.014	.014	.016
.016	.016	.016	.017	.017
.017	.017	.017	.017	.017
.017	.019	.019	.022	.023

```
        *****   HISTOGRAM   *****
   12                          *
   11               *          *
   10               *          *
    9               *          *
    8               *          *
    7               *          *
    6               *    *    *    *
    5               *    *    *    *
    4          *    *    *    *    *
    3          *    *    *    *    *
    2     *    *    *    *    *    *         *
    1     *    *    *    *    *    *         *    *    *
     ----------------------------------------------------
NUMBER    2    4   11    6    6   12    0    2    1    1
CLASS

 START    .007  STOP    .024 SIZE OF INTERVAL          .0017
 CALCULATED MEAN=     .01391 CALCULATED VARIANCE=     .00001
```

****

HYPOTHESIS STATEMENT

NULL HYPOTHESIS= POPULATION IS NORMAL WITH TRUE MEAN= .0139
ALTERNATIVE HYPOTHESIS= POPULATION IS NOT NORMAL WITH TRUE MEAN= .0139

****
NUMBER OF OBSERVATIONS= 45

KOLMOGOROV - SMIRNOV TEST

CELLS	RANGE FROM	RANGE TO	OBSERVED	OBSERVED FREQUENCY	CUMULATIVE OBSERVED FREQUENCY	THEORETICAL FREQUENCY	CUMULATIVE THEORETICAL FREQUENCY	KOLMOGOROV - SMIRNOV STATISTIC
1	-999.99902	.00860	2.00000	.04444	.04444	.02298	.02298	.02146
2	.00860	.01020	4.00000	.08889	.13333	.11895	.14194	.00860
3	.01020	.01180	2.00000	.04444	.17778	.12912	.27105	.09328
4	.01180	.01340	15.00000	.33333	.51111	.17028	.44133	.06978
5	.01340	.01500	6.00000	.13333	.64444	.18208	.62341	.02104
6	.01500	.01660	4.00000	.08889	.73333	.15786	.78127	.04793
7	.01660	.01820	8.00000	.17778	.91111	.11097	.89224	.01887
8	.01820	.01980	2.00000	.04444	.95556	.06325	.95549	.00007
9	.01980	.02140	.00000	.00000	.95556	.02923	.98471	.02916
10	.02140	.02300	2.00000	.04444	1.00000	.01095	.99566	.00433

DEGREES OF FREEDOM= 10
MU= .013911109 SIGMA 2= .000011992

THE KOLMOGOROV - SMIRNOV STATISTIC = .09328

DRYING

ORDERED DATA

.050	.083	.083	.083	.083
.083	.083	.083	.083	.083
.083	.083	.083	.083	.083
.083	.083	.083	.100	.117
.117	.117	.133	.133	.133
.133	.133	.133	.133	.167
.167	.167	.167	.167	.167
.167	.167	.167	.167	.183
.250	.250	.250	.250	1.833

```
        *****   HISTOGRAM   *****

        EACH * REPRESENTS  2 POINTS
    40   *
    38   *
    36   *
    34   *
    32   *
    30   *
    28   *
    26   *
    24   *
    22   *
    20   *
    18   *
    16   *
    14   *
    12   *
    10   *
     8   *
     6   *
     4   *    *
     2   *    *
      ----------------------------------------*
NUMBER   40   4    0    0    0    0    0    0    0    1
CLASS

START    .000  STOP    1.900 SIZE OF INTERVAL          .1900
CALCULATED MEAN=      .16731 CALCULATED VARIANCE=     .06721
```

****

HYPOTHESIS STATEMENT

NULL HYPOTHESIS= POPULATION IS EXP   WITH TRUE MEAN=   .1673
ALTERNATIVE HYPOTHESIS=   POPULATION IS NOT EXP   WITH TRUE MEAN=   .1673

****
NUMBER OF OBSERVATIONS=   45

KOLMOGOROV - SMIRNOV TEST

CELLS	RANGE FROM	TO	OBSERVED	OBSERVED FREQUENCY	CUMULATIVE OBSERVED FREQUENCY	THEORETICAL FREQUENCY	CUMULATIVE THEORETICAL FREQUENCY	KOLMOGOROV - SMIRNOV STATISTIC
1	.00000	.22830	40.00000	.88889	.88889	.74450	.74450	.14439
2	.22830	.40660	4.00000	.08889	.97778	.16748	.91198	.06580
3	.40660	.58490	.00000	.00000	.97778	.05770	.96968	.00810
4	.58490	.76320	.00000	.00000	.97778	.01988	.98955	.01178
5	.76320	.94150	.00000	.00000	.97778	.00685	.99640	.01862
6	.94150	1.11980	.00000	.00000	.97778	.00236	.99876	.02098
7	1.11980	1.29810	.00000	.00000	.97778	.00081	.99957	.02180
8	1.29810	1.47640	.00000	.00000	.97778	.00028	.99985	.02208
9	1.47640	1.65470	.00000	.00000	.97778	.00010	.99995	.02217
10	1.65470	1.83300	.00000	.00000	.97778	.00003	.99998	.02220

THE KOLMOGOROV - SMIRNOV STATISTIC =   .14439

DEGREES OF FREEDOM=   10
THETA=   .16731172

TONS/TRIP

ORDERED DATA

.257	.318	.329	.347	.381
.410	.477	.533	.533	.540
.553	.582	.588	.610	.659
.685	.706	.709	.721	.739
.764	.764	.795	.804	.838
.841	.841	.841	.869	.869
.918	.948	.963	1.010	1.023
1.051	1.059	1.063	1.080	1.080
1.111	1.124	1.142	1.142	1.155
1.156	1.172	1.211	1.211	1.211
1.216	1.332	1.332	1.332	1.332
1.441	1.441	1.442	1.512	1.525
1.650	1.682	1.695	1.695	1.746
1.756	1.780	1.814	1.893	1.913
1.920	2.241	2.241	2.258	2.345
2.345	2.400	2.416	2.457	2.521
2.909	2.982	2.982	3.009	3.012
3.025	3.025			

```
        *****   HISTOGRAM   *****
 13                      *
 12                      *
 11                  *   *
 10              *   *   *
  9              *   *   *   *
  8              *   *   *   *
  7          *   *   *   *   *                                       *
  6          *   *   *   *   *           *                           *
  5      *   *   *   *   *   *   *   *   *           *               *
  4      *   *   *   *   *   *   *   *   *           *               *
  3      *   *   *   *   *   *   *   *   *       *   *               *
  2      *   *   *   *   *   *   *   *   *       *   *               *
  1      *   *   *   *   *   *   *   *   *       *   *   *           *
    -----------------------------------------------------------------
NUMBER   5   7  10  11  13   9   5   5   6   0   3   5   1   0   7
CLASS

START    .200   STOP   3.100 SIZE OF INTERVAL         1933
CALCULATED MEAN=    1.33736 CALCULATED VARIANCE=    .56191
```

****

HYPOTHESIS STATEMENT

NULL HYPOTHESIS= POPULATION IS GAMMA WITH TRUE MEAN= 1.3374
ALTERNATIVE HYPOTHESIS= POPULATION IS NOT GAMMA WITH TRUE MEAN= 1.3374

****
NUMBER OF OBSERVATIONS= 87

KOLMOGOROV - SMIRNOV TEST

CELLS	RANGE FROM	TO	OBSERVED	OBSERVED FREQUENCY	CUMULATIVE OBSERVED FREQUENCY	THEORETICAL FREQUENCY	CUMULATIVE THEORETICAL FREQUENCY	KOLMOGOROV - SMIRNOV STATISTIC
1	.00000	.53380	9.00000	.10345	.10345	.01743	.01743	.08602
2	.53380	.81060	15.00000	.17241	.27586	.24699	.26442	.01144
3	.81060	1.08740	16.00000	.18391	.45977	.16973	.43414	.02563
4	1.08740	1.36420	15.00000	.17241	.63218	.15421	.58835	.04383
5	1.36420	1.64100	5.00000	.05747	.68966	.12485	.71320	.02355
6	1.64100	1.91780	10.00000	.11494	.80460	.09367	.80688	.00228
7	1.91780	2.19460	1.00000	.01149	.81609	.06659	.87346	.05737
8	2.19460	2.47140	8.00000	.09195	.90805	.04546	.91893	.01088
9	2.47140	2.74820	1.00000	.01149	.91954	.03009	.94901	.02947
10	2.74820	3.02500	7.00000	.08046	1.00000	.01942	.96843	.03157

THE KOLMOGOROV - SMIRNOV STATISTIC = .08602

DEGREES OF FREEDOM= 10
ALPHA= 3.182927132 BETA= .420165420

BREAKDOWN LENGTH

ORDERED DATA

.006	.006	.006	.007	.008
.008	.009	.009	.009	.009
.009	.009	.009	.010	.010
.010	.010	.010	.011	.011
.012	.012	.012	.012	.012
.012	.012	.013	.013	.014
.014	.014	.014	.014	.014
.014	.015	.015	.015	.015
.016	.017	.017	.020	.021

```
        *****   HISTOGRAM   *****
   11                         *
   10                         *
    9        *         *      *
    8        *         *      *
    7        *         *      *
    6        *         *      *
    5        *    *    *      *
    4    *   *    *    *      *
    3    *   *    *    *      *    *
    2    *   *    *    *   *  *    *
    1    *   *    *    *   *  *    *         *    *
      ----------------------------------------------
NUMBER   4   9    5    9   2  11   3    0    1    1

CLASS

 START    .006  STOP    .022 SIZE OF INTERVAL          .0016
 CALCULATED MEAN=     .01189 CALCULATED VARIANCE=     .00001
```

****

HYPOTHESIS STATEMENT

NULL HYPOTHESIS= POPULATION IS NORMAL WITH TRUE MEAN= .0119
ALTERNATIVE HYPOTHESIS= POPULATION IS NOT NORMAL WITH TRUE MEAN= .0119

****
NUMBER OF OBSERVATIONS= 45

KOLMOGOROV - SMIRNOV TEST

CELLS	RANGE FROM	TO	OBSERVED	OBSERVED FREQUENCY	CUMULATIVE OBSERVED FREQUENCY	THEORETICAL FREQUENCY	CUMULATIVE THEORETICAL FREQUENCY	KOLMOGOROV - SMIRNOV STATISTIC
1	-999.99902	.00750	4.00000	.08889	.08889	.04433	.04433	.04456
2	.00750	.00900	9.00000	.20000	.28889	.15748	.20181	.08708
3	.00900	.01050	5.00000	.11111	.40000	.14221	.34402	.05598
4	.01050	.01200	9.00000	.20000	.60000	.16880	.51281	.08719
5	.01200	.01350	2.00000	.04444	.64444	.16650	.67931	.03487
6	.01350	.01500	11.00000	.24444	.88889	.13648	.81579	.07310
7	.01500	.01650	1.00000	.02222	.91111	.09296	.90875	.00236
8	.01650	.01800	2.00000	.04444	.95556	.05262	.96136	.00581
9	.01800	.01950	.00000	.00000	.95556	.02475	.98611	.03055
10	.01950	.02100	2.00000	.04444	1.00000	.00967	.99578	.00422

THE KOLMOGOROV - SMIRNOV STATISTIC = .08719

DEGREES OF FREEDOM= 10
MU= .011888888 SIGMA 2= .000011965

APPENDIX B

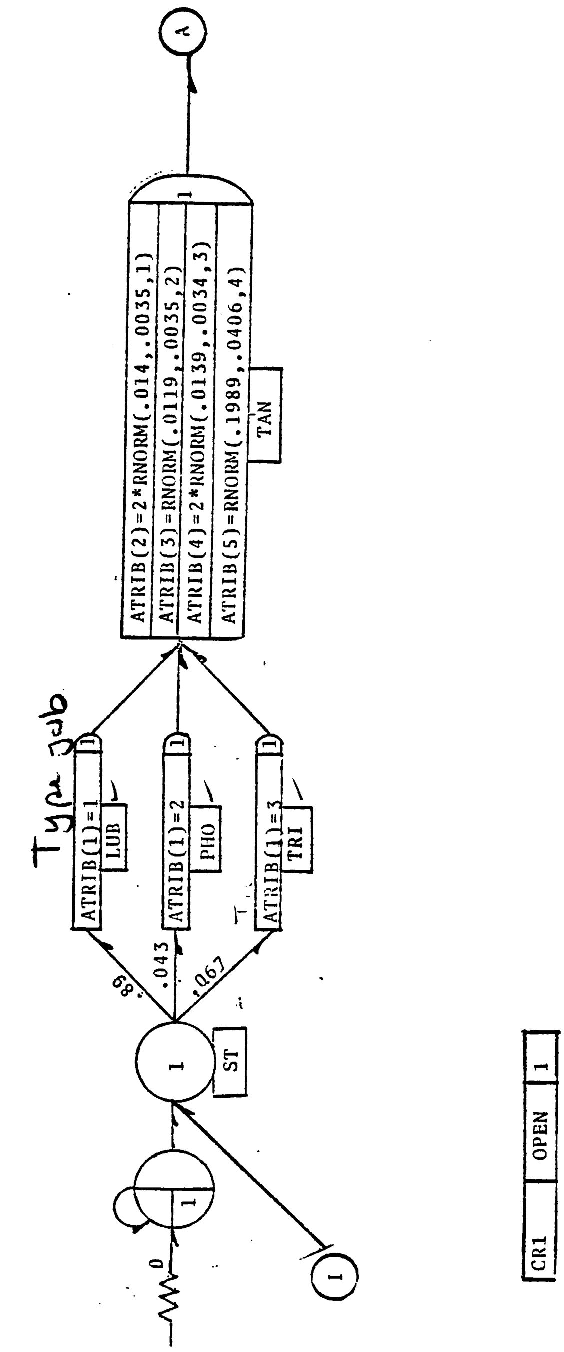
PRESENT SYSTEM SLAM ATTRIBUTES, LISTING, AND NETWORK

ATTRIBUTE DESCRIPTION OF PRESENT SYSTEM

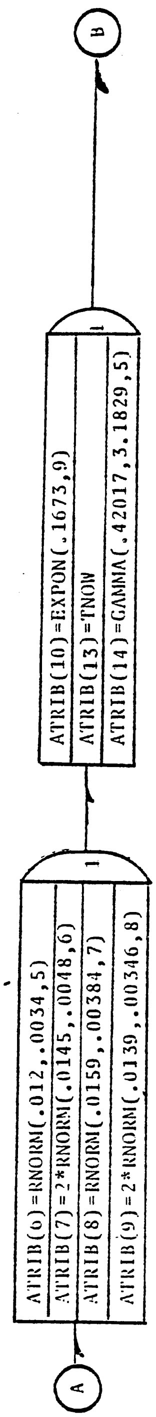
Attribute	Description
1	Type of Operation
2	Caustic Dipping
3	Cold Water Dipping
4	Acid Dipping
5	Acid Soak
6	Hot Water Dipping
7	Phosphate Dipping
8	Neutralizer Dipping
9	Soap Dipping
10	Drying
11	Breakdown Time
12	Breakdown Length
13	Time an Entity Starts in the System
14	Tons/Trip

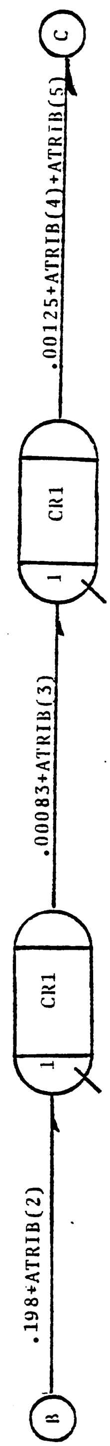
```
GEN,J. R. LEWIS,TANKS,1/04/84,10;
LIMITS,2,14,100;
INIT,0,360;
INTLC,XX(1)=0;
INTLC,XX(2)=0;
TIMST,XX(1),NUMBER IN SYS. 1;
TIMST,XX(2),NUMBER OF BRKDWNS.;
TIMST,XX(3),TON OUTPUT,;
NETWORK;
        GATE/CR1,OPEN,1;
        CREATE;
ST      GOON,1;
        ACT,,.89,LUB;
        ACT,,.043,PHO;
        ACT,,.067,TRI;
LUB     ASSIGN,ATRIB(1)=1;
        ACT,,,TAN;
PHO     ASSIGN,ATRIB(1)=2;
        ACT,,,TAN;
TRI     ASSIGN,ATRIB(1)=3;
        ACT,,,TAN;
TAN     ASSIGN,ATRIB(2)=2*RNORM(.014,.0035,1);
        ASSIGN,ATRIB(3)=RNORM(.0119,.0035,2);
        ASSIGN,ATRIB(4)=2*RNORM(.0139,.0034,3);
        ASSIGN,ATRIB(5)=RNORM(.1989,.0406,4);
        ASSIGN,ATRIB(6)=RNORM(.012,.0034,5);
        ASSIGN,ATRIB(7)=2*RNORM(.0145,.0048,6);
        ASSIGN,ATRIB(8)=RNORM(.0159,.00384,7);
        ASSIGN,ATRIB(9)=2*RNORM(.0139,.00346,8);
        ASSIGN,ATRIB(10)=EXPON(.1673,9);
        ASSIGN,ATRIB(13)=TNOW;
        ASSIGN,ATRIB(14)=GAMMA(.42017,3.18293,5);
        ACT;
        GOON;
        ACT,.198+ATRIB(2);                        CAUSTIC DIP AND SOAK
        AWAIT,CR1;
        ACT,.00083+ATRIB(3);                      COLD WATER RINSE
        AWAIT,CR1;
        ACT,.00125+ATRIB(4)+ATRIB(5);             ACID DIP AND SOAK
        AWAIT,CR1;
        ACT,.00125+ATRIB(3);                      COLD WATER RINSE
        AWAIT,CR1;
        ACT,.005+ATRIB(6);                        HOT WATER RINSE
        AWAIT,CR1,1;
        ACT,,ATRIB(1).EQ.3,T;
        ACT,.0852+ATRIB(7);                       PHOSPHATE
        AWAIT,CR1;
        ACT,.0019+ATRIB(3);                       COLD WATER RINSE
        AWAIT,CR1,1;
        ACT,,ATRIB(1).EQ.2,P;
        ACT,.0006+ATRIB(8);                       NEUTRALIZER
        AWAIT,CR1;
        ACT,.085+ATRIB(9),,DRY;                   SOAP
T       GOON;
        ACT,.0058,,DRY;                           TRICK
P       GOON;
        ACT,.0021,,DRY;                           PHOSPHATE
DRY     AWAIT,CR1;
        ACT,.04;
        AWAIT,CR1,2;
        ACT,,,EN;
        ACT,.0158;
```

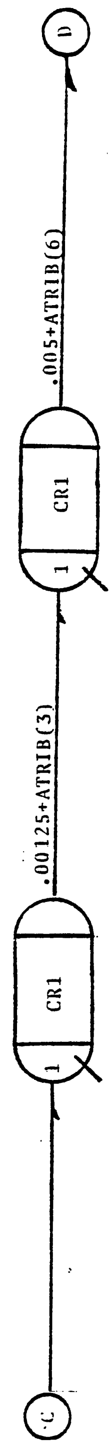
```
        AWAIT,CR1;
        COLCT,INT(13),TANK TIME,15/.5/.1;
        ACT,,,ST;
 EN     GOON;
        ACT,ATRIB(10);
        COLCT,INT(13),TOTAL TIME,15/.5/.1;
        ASSIGN,XX(1)=XX(1)+1;
        ASSIGN, XX(3)=XX(3)+ATRIB(14);
        TERM;
        CREATE;                                 NETWORK TO RUN BREAKDOWNS
 SH     GOON,1;
        ACT,,.83,GD;
        ACT,,.17,DN;                            DETERMINE IF BRKDWN OCCURS
 GD     GOON;
        ACT,12,,SH;
 DN     ASSIGN,ATRIB(11)=UNFRM(0,12,10);
        ASSIGN,ATRIB(12)=EXPON(1.023,9);
        ASSIGN,XX(2)=XX(2)+1,1;
        ACT,ATRIB(11);
        CLOSE,CR1;
        GOON,1;
        ACT,,ATRIB(11)+ATRIB(12).GT.12,E;
        ACT,ATRIB(12);
        OPEN,CR1;
        ACT,12-ATRIB(11)-ATRIB(12),,SH;
 E      GOON;
        OPEN,CR1;
        ACT,,,SH;
        END;
 FIN;
```

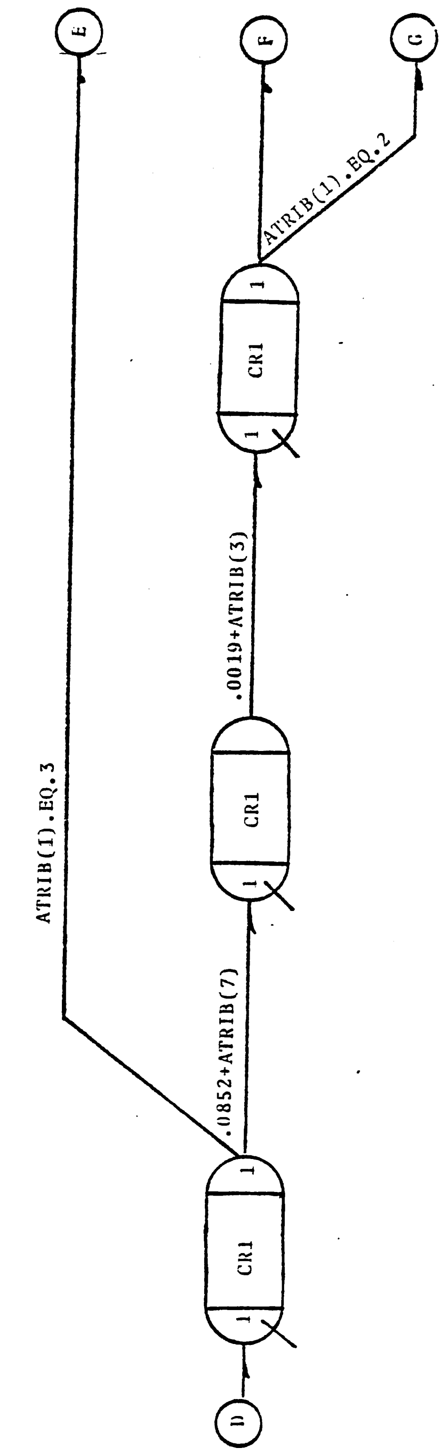


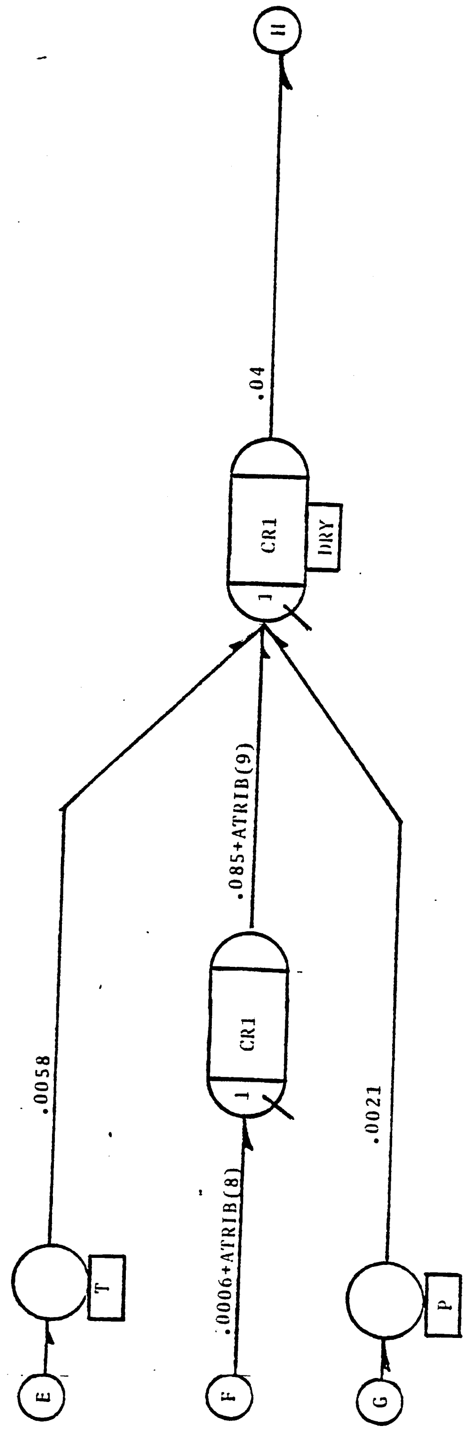
ATRIB(2)=2*RNORM(.014,.0035,1)
ATRIB(3)=RNORM(.0119,.0035,2)
ATRIB(4)=2*RNORM(.0139,.0034,3)
ATRIB(5)=RNORM(.1989,.0406,4)
TAN
A
Type job
ATRIB(1)=1
LUB
ATRIB(1)=2
PHO
ATRIB(1)=3
TRI
.89
.043
.067
ST
0
I
CR1
OPEN
1

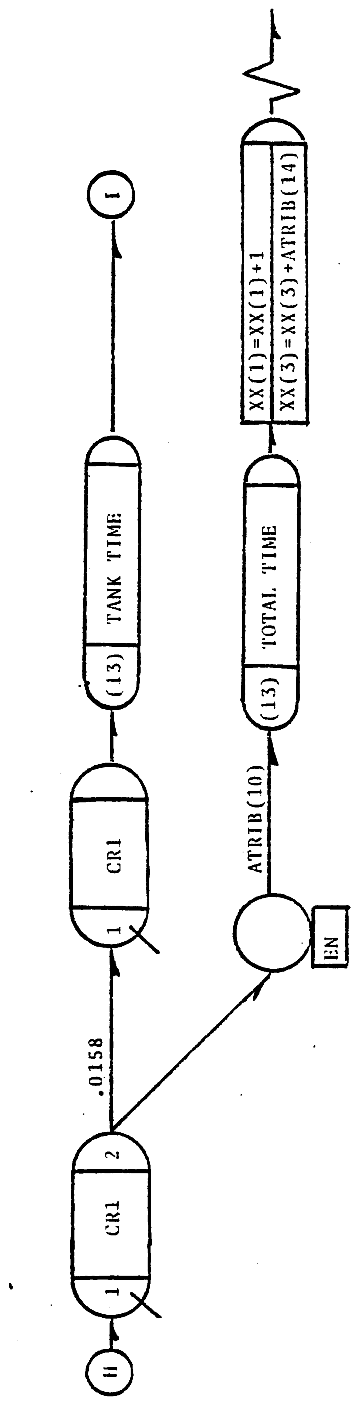

B
ATRIB(10)=EXPON(.1673,9)
ATRIB(13)=TNOW
ATRIB(14)=GAMMA(.42017,3.1829,5)
1
ATRIB(6)=RNORM(.012,.0034,5)
ATRIB(7)=2*RNORM(.0145,.0048,6)
ATRIB(8)=RNORM(.0159,.00384,7)
ATRIB(9)=2*RNORM(.0139,.00346,8)
1
A


B
.198+ATRIB(2)
1
CR1
.00083+ATRIB(3)
1
CR1
.00125+ATRIB(4)+ATRIB(5)
C

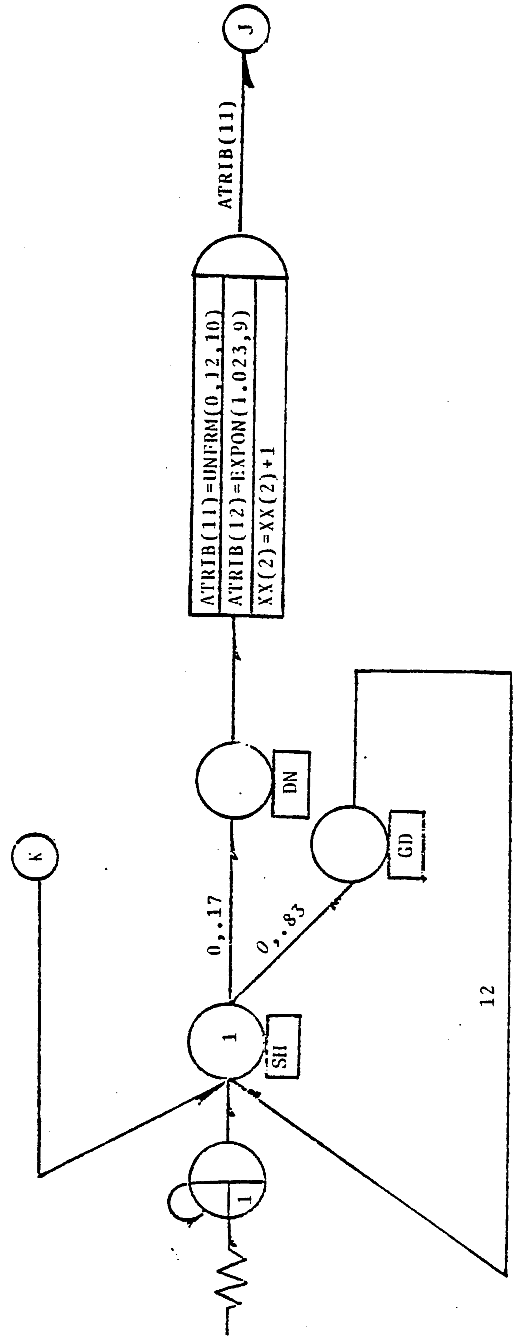

C
1
CR1
.00125+ATRIB(3)
1
CR1
.005+ATRIB(6)
D

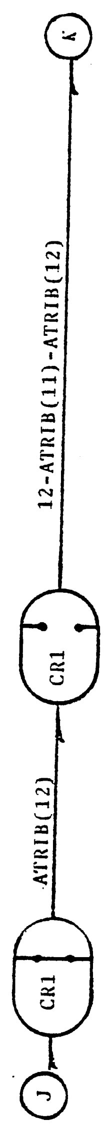

D
CR1
1
1
.0852+ATRIB(7)
ATRIB(1).EQ.3
E
CR1
1
.0019+ATRIB(3)
CR1
1
1
ATRIB(1).EQ.2
F
G


E
T
.0058
F
.0006+ATRIB(8)
1
CR1
.085+ATRIB(9)
G
P
.0021
1
CR1
DRY
.04
H



H
1
CR1
2
.0158
1
CR1
(13)
TANK TIME
I
EN
ATRIB(10)
(13)
TOTAL TIME
XX(1)=XX(1)+1
XX(3)=XX(3)+ATRIB(14)


J
ATRIB(11)
ATRIB(11)=UNFRM(0,12,10)
ATRIB(12)=EXPON(1.023,9)
XX(2)=XX(2)+1
DN
GD
K
0,.17
0,.83
1
SH
12
1



J
CR1
ATRIB(12)
CR1
12-ATRIB(11)-ATRIB(12)
K

APPENDIX C

TWO CRANE ONE OPERATOR SLAM ATTRIBUTES, LISTING, AND NETWORK

ATTRIBUTE DESCRIPTION OF TWO CRANE
ONE OPERATOR MODEL

Attribute	Description
1	Type of Operation, Crane 1
2	Caustic Dipping, Crane 1
3	Cold Water Dipping, Crane 1
4	Acid Dipping, Crane 1
5	Acid Soak, Crane 1
6	Hot Water Dipping, Crane 1
7	Phosphate Dipping, Crane 1
8	Neutralizer Dipping, Crane 1
9	Soap Dipping, Crane 1
10	Drying, Crane 1
11	Breakdown Time, Crane 1
12	Breakdown Length, Crane 1
13	Type of Operation, Crane 2
14	Caustic Dipping, Crane 2
15	Cold Water Dipping, Crane 2
16	Acid Dipping, Crane 2
17	Acid Soak, Crane 2
18	Hot Water Dipping, Crane 2
19	Phosphate Dipping, Crane 2
20	Neutralizer Dipping, Crane 2
21	Soap Dipping, Crane 2
22	Drying, Crane 2
23	Breakdown Time, Crane 2
24	Breakdown Length, Crane 2
25	Time Entity Starts in System, Crane 1
26	Time Entity Starts in System, Crane 2
29	Tons/Trip, Crane 1
30	Tons/Trip, Crane 2

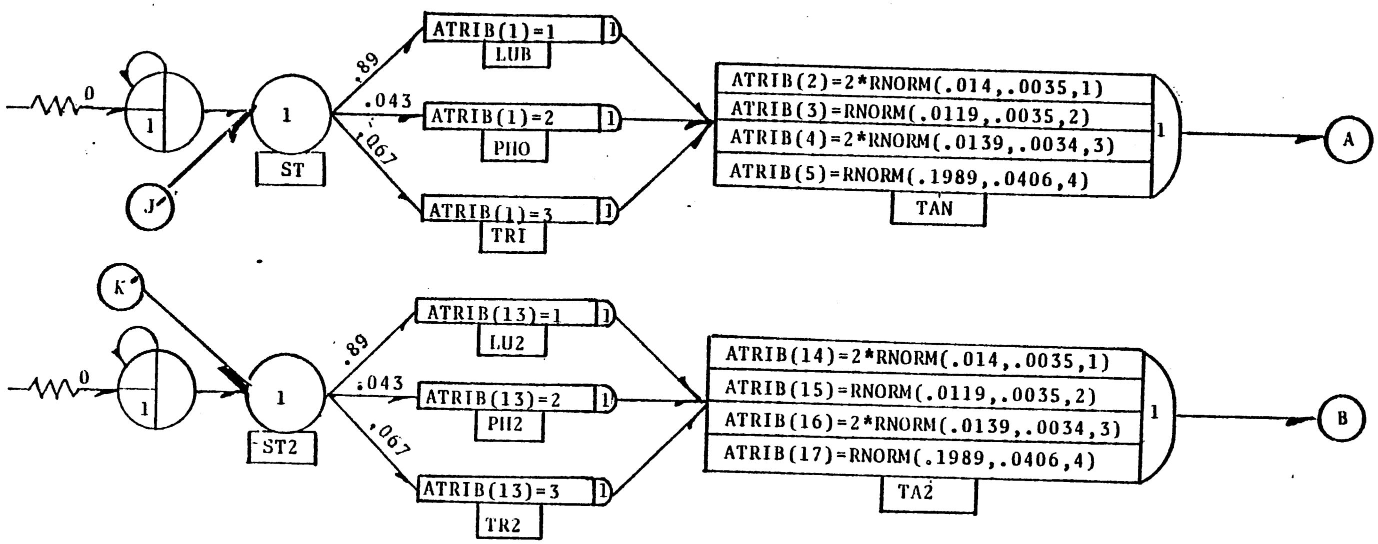
```
GEN,J. R. LEWIS,TANKS,1/04/84,10;
LIMITS,11,30,10;
INIT,0,360;
INTLC,XX(1)=0;
INTLC,XX(2)=0;
INTLC,XX(3)=0;
TIMST,XX(1),NUMBER IN SYS. 1;
TIMST,XX(2),NUMBER OF BRKDWNS.;
TIMST,XX(3),NUMBER OF BRKDWNS IN SYS 2;
TIMST,XX(4),TON OUTPUT;
NETWORK;
        GATE/CR1,OPEN,1;
        GATE/CR2,OPEN,2;
        GATE/MOV,CLOSE,3;
        GATE/SC2,CLOSE,4;
        GATE/C2,OPEN,5;
        GATE/P2,OPEN,6;
        GATE/SO2,OPEN,7;
        GATE/SC1,OPEN,8;
        GATE/ACID,OPEN,9;
        GATE/PAS1,OPEN,10;
        GATE/PAS2,OPEN,11;
        CREATE;
ST      GOON,1;
        ACT,,.89,LUB;
        ACT,,.043,PHO;
        ACT,,.067,TRI;
LUB     ASSIGN,ATRIB(1)=1;
        ACT,,,TAN;
PHO     ASSIGN,ATRIB(1)=2;
        ACT,,,TAN;
TRI     ASSIGN,ATRIB(1)=3;
        ACT,,,TAN;
TAN     ASSIGN,ATRIB(2)=2*RNORM(.014,.0035,1);
        ASSIGN,ATRIB(3)=RNORM(.0119,.0035,2);
        ASSIGN,ATRIB(4)=2*RNORM(.0139,.0034,3);
        ASSIGN,ATRIB(5)=RNORM(.1989,.0406,4);
        ASSIGN,ATRIB(6)=RNORM(.012,.0034,5);
        ASSIGN,ATRIB(7)=2*RNORM(.0145,.0048,6);
        ASSIGN,ATRIB(8)=RNORM(.0159,.00384,7);
        ASSIGN,ATRIB(9)=2*RNORM(.0139,.00346,8);
        ASSIGN,ATRIB(10)=EXPON(.1673,9);
        ASSIGN,ATRIB(25)=TNOW;
        ASSIGN,ATRIB(29)=GAMMA(.42017,3.18293,5);
        AWAIT,SC1;
        ACT;
        CLOSE,SC2;
        ACT,.114+ATRIB(2);
        AWAIT,CR1;
        OPEN,SC2;
        CLOSE,C2;
        ACT,.083;                                   CAUSTIC SOAK
        AWAIT,CR1;
        AWAIT,SC1;
        CLOSE,SC2;
        OPEN,C2;
        ACT,.00083+ATRIB(3);                        COLD WATER RINSE
        AWAIT,CR1;
        ACT,.00125+ATRIB(4);                        ACID DIP AND SOAK
        OPEN,SC2;
        CLOSE,ACID;
        ACT,ATRIB(5);
```

```
        AWAIT,SC1;
        CLOSE,SC2;
        AWAIT,CR1;
        ACT,.00125+ATRIB(3);                    COLD WATER RINSE
        AWAIT,CR1;
        ACT,.005+ATRIB(6);                      HOT WATER RINSE
        OPEN,ACID;
        CLOSE,PAS1;
        AWAIT,CR1,1;
        ACT,,ATRIB(1).EQ.3,T;
        ACT,.0019+ATRIB(7);
        AWAIT,CR1;
        OPEN,SC2;
        CLOSE,P2;
        ACT,.083;                               PHOSPHATE SOAK
        AWAIT,CR1;
        OPEN,P2;
        AWAIT,SC1;
        CLOSE,SC2;
        ACT,.0019+ATRIB(3);                     COLD WATER RINSE
        CLOSE,PAS2;
        AWAIT,CR1,1;
        ACT,,ATRIB(1).EQ.2,P;
        ACT,.0006+ATRIB(8);                     NEUTRALIZER
        AWAIT,CR1;
        ACT,.0017+ATRIB(9);                     SOAP
        AWAIT,CR1;
        OPEN,SC2;
        CLOSE,SO2;
        ACT,.083;                               SOAP SOAK
        AWAIT,CR1;
        ACT,,,DRY;
T       GOON;
        ACT,.0058;                              TRICK
        AWAIT,CR1;
        OPEN,SC2;
        ACT,,,DRY;
P       GOON;
        ACT,.0021;                              PHOSPHATE
        AWAIT,CR1;
        OPEN,SC2;
        ACT,,,DRY;
DRY     GOON;
        OPEN,PAS1;
        OPEN,PAS2;
        ACT,.04;
        AWAIT,CR1;
        OPEN,SO2;
        AWAIT,SC1;
        CLOSE,SC2;
        OPEN,SC2;
        COLCT,INT(25),TANK TIME SYS 1,15/.5/.1;
        GOON,2;
        ACT,,,EN;
        ACT;
        AWAIT,MOV;
        CLOSE,SC2;
        CLOSE,MOV;
        ACT,.0158;
        AWAIT,CR1;
        ACT,,,ST;
EN      GOON;
        ACT,ATRIB(10);
        COLCT,INT(25),TOTAL TIME SYS 1,15/.5/.1;
OUT     ASSIGN,XX(1)=XX(1)+1;
        ASSIGN,XX(4)=XX(4)+ATRIB(29)+ATRIB(30);
```

```
        TERM;
        CREATE;                                NETWORK TO RUN BREAKDOWNS
SH      GOON,1;
        ACT,,.83,GD;
        ACT,,.17,DN;                           DETERMINE IF BRKDWN OCCURS
GD      GOON;
        ACT,12,,SH;
DN      ASSIGN,ATRIB(11)=UNFRM(0,12,10);
        ASSIGN,ATRIB(12)=EXPON(1.023,9);
        ASSIGN,XX(2)=XX(2)+1,1;
        ACT,ATRIB(11);
        CLOSE,CR1;
        ACT,ATRIB(12);
        OPEN,CR1;
        ACT,12-ATRIB(11)-ATRIB(12),,SH;
        CREATE;
ST2     GOON,1;
        ACT,,.89,LU2;
        ACT,,.043,PH2;
        ACT,,.067,TR2;
LU2     ASSIGN,ATRIB(13)=1;
        ACT,,,TA2;
PH2     ASSIGN,ATRIB(13)=2;
        ACT,,,TA2;
TR2     ASSIGN,ATRIB(13)=3;
        ACT,,,TA2;
TA2     ASSIGN,ATRIB(14)=2*RNORM(.014,.0035,1);
        ASSIGN,ATRIB(15)=RNORM(.0119,.0035,2);
        ASSIGN,ATRIB(16)=2*RNORM(.0139,.0034,3);
        ASSIGN,ATRIB(17)=RNORM(.1989,.0406,4);
        ASSIGN,ATRIB(18)=RNORM(.012,.0034,5);
        ASSIGN,ATRIB(19)=2*RNORM(.0145,.0048,6);
        ASSIGN,ATRIB(20)=RNORM(.0159,.00384,7);
        ASSIGN,ATRIB(21)=2*RNORM(.0139,.00346,8);
        ASSIGN,ATRIB(22)=EXPON(.1673,9);
        ASSIGN,ATRIB(26)=TNOW;
        ASSIGN,ATRIB(30)=GAMMA(.42017,3.18293,5);
        AWAIT,SC2;
        CLOSE,SC1;
        ACT,.114;
        AWAIT,CR2;
        OPEN,SC1;
        AWAIT,C2;
        AWAIT,SC2;
        CLOSE,SC1;
        ACT,ATRIB(14);
        GOON;
        ACT,.083;                                      CAUSTIC
        OPEN,SC1;
        AWAIT,CR2;
        AWAIT,ACID;
        AWAIT,SC2;
        CLOSE,SC1;
        ACT,.00083+ATRIB(15);                          COLD WATER RINSE
        AWAIT,CR2;
        ACT,.00125+ATRIB(16);                          ACID DIP AND SOAK
        OPEN,SC1;
        ACT,ATRIB(17);
        AWAIT,SC2;
        CLOSE,SC1;
        AWAIT,CR2;
        ACT,.00125+ATRIB(15);                          COLD WATER RINSE
        AWAIT,CR2;
        ACT,.005+ATRIB(18);                            HOT WATER RINSE
        AWAIT,CR2,1;
        ACT,,ATRIB(13).EQ.3,T2;
```

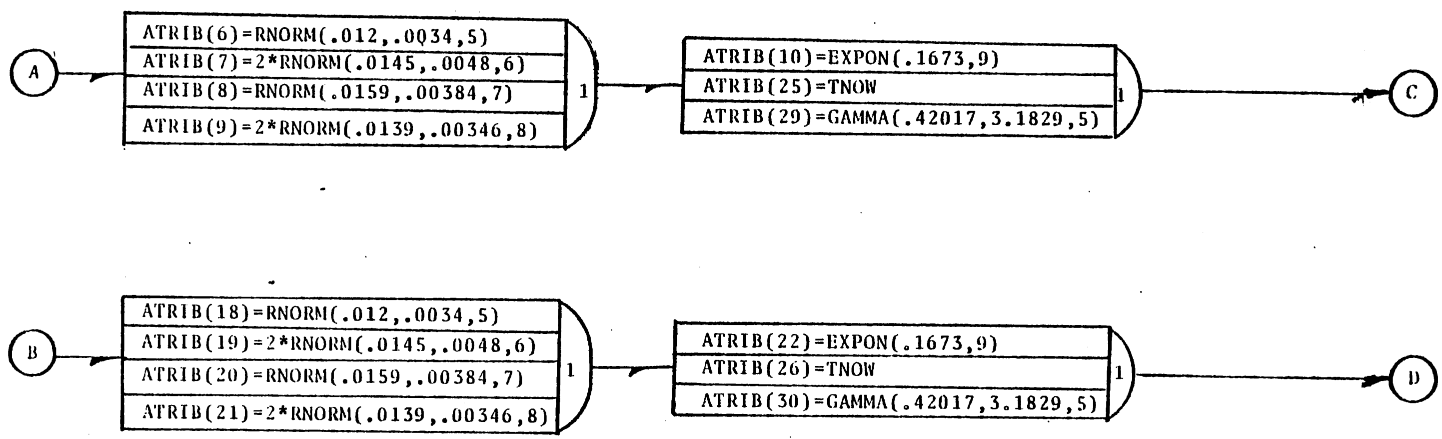
```
        ACT;
        AWAIT,P2;
        AWAIT,SC2;
        CLOSE,SC1;
        ACT,.0019+ATRIB(19);                     PHOSPHATE
        AWAIT,CR2;
        OPEN,SC1;
        ACT,.083;                                PHOSPHATE SOAK
        AWAIT,CR2;
        AWAIT,SC2;
        CLOSE,SC1;
        ACT,.0019+ATRIB(15);                     COLD WATER RINSE
        AWAIT,CR2,1;
        ACT,,ATRIB(13).EQ.2,PP;
        ACT,.0006+ATRIB(20);                     NEUTRALIZER
        OPEN,SC1;
        AWAIT,CR2;
        AWAIT,SO2;
        AWAIT,SC2;
        CLOSE,SC1;
        ACT,.0017+ATRIB(21);                     SOAP
        AWAIT,CR2;
        OPEN,SC1;
        ACT,.083;                                SOAP SOAK
        AWAIT,CR2;
        ACT,,,DR2;
T2      GOON;
        OPEN,SC1;
        AWAIT,PAS1;
        AWAIT,SC2;
        CLOSE,SC1;
        ACT,.0058;                               TRICK
        AWAIT,CR2;
        OPEN,SC1;
        ACT,,,DR2;
PP      GOON;
        OPEN,SC1;
        AWAIT,PAS2;
        AWAIT,SC2;
        CLOSE,SC1;
        ACT,.0021;                               PHOSPHATE
        AWAIT,CR2;
        OPEN,SC1;
        ACT,,,DR2;
DR2     GOON;
        AWAIT,SC2;
        CLOSE,SC1;
        ACT,.04;
        AWAIT,CR2;
        OPEN,SC1;
        COLCT,INT(26),TANK TIME SYS 2,15/.5/.1;
        GOON,2;
        ACT,,,E2;
        ACT;
        OPEN,MOV;
        ACT,,,ST2;
E2      GOON;
        ACT,ATRIB(22);
        COLCT,INT(26),TOTAL TIME SYS 2,15/.5/.1;
        ACT,,,OUT;
        CREATE;                         NETWORK TO RUN BREAKDOWNS
SH2     GOON,1;
        ACT,,.83,GD2;
        ACT,,.17,DN2;                    DETERMINE IF BRKDOWN OCCURS
GD2     GOON;
        ACT,12,,SH2;
```

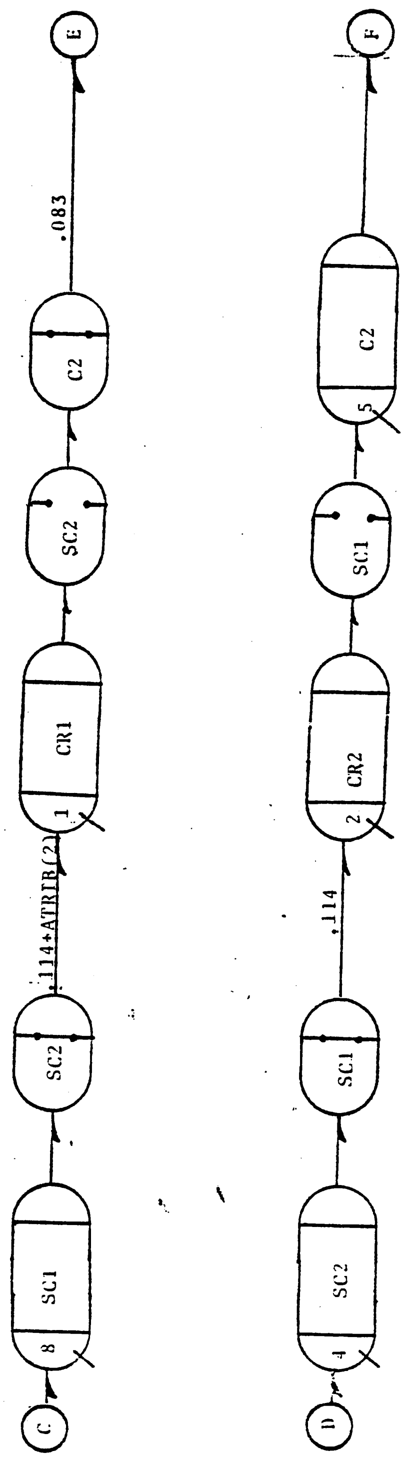
```
DN2    ASSIGN,ATRIB(27)=UNFRM(0,12,10);
       ASSIGN,ATRIB(28)=EXPON(1.023,9);
       ASSIGN,XX(3)=XX(3)+1,1;
       ACT,ATRIB(27);
       CLOSE,CR2;
       ACT,ATRIB(28);
       OPEN,CR2;
       ACT,12-ATRIB(27)-ATRIB(28),,SH2;
       END;
FIN;
```

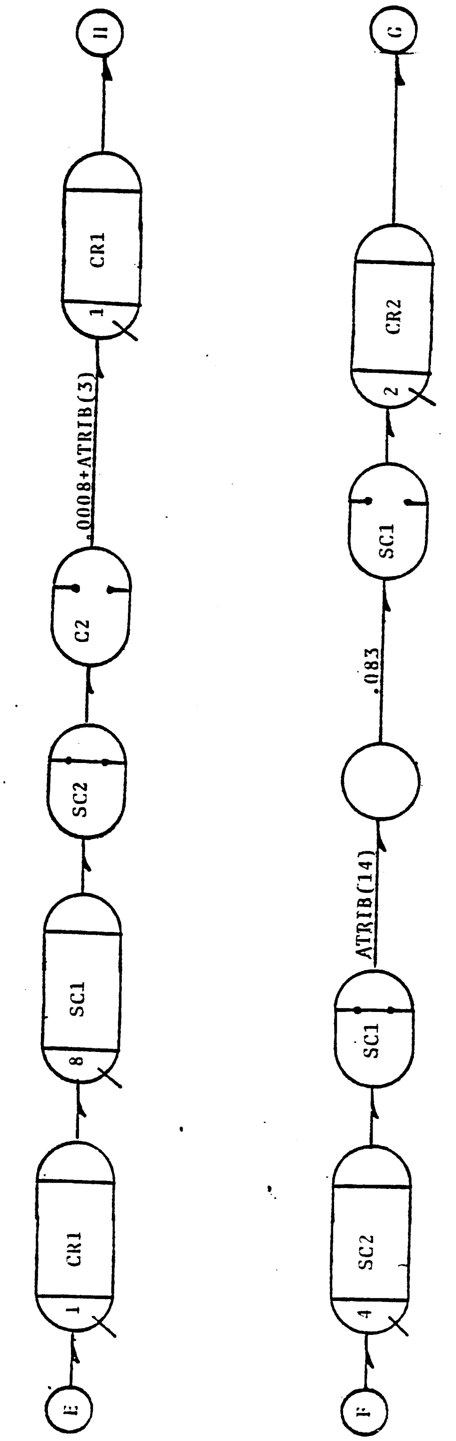


CR1	OPEN	1
CR2	OPEN	2
MOV	CLOSE	3
SC2	CLOSE	4
C2	OPEN	5
P2	OPEN	6

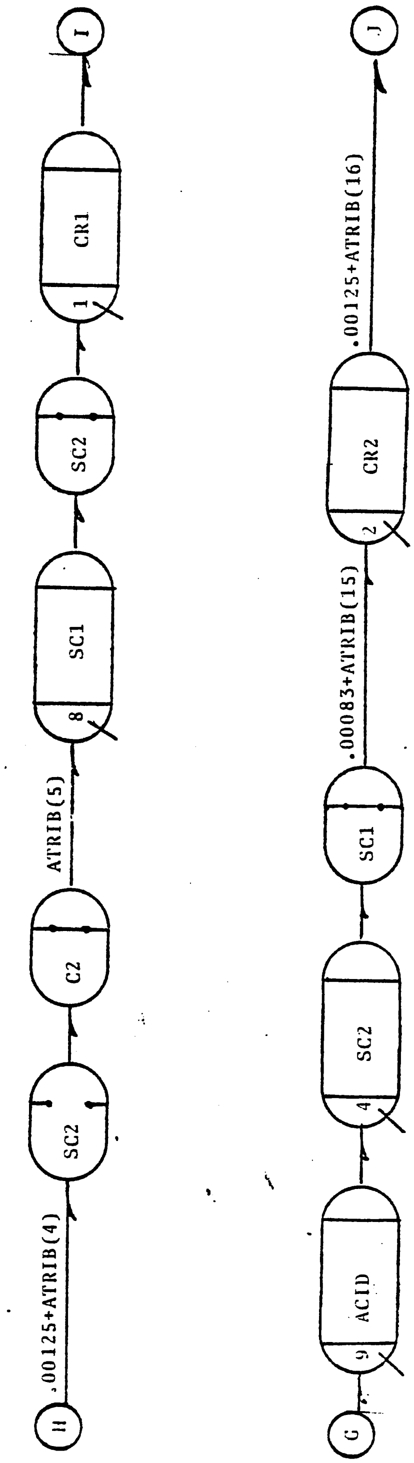
SO2	OPEN	7
SC1	OPEN	8
ACID	OPEN	9
PAS1	OPEN	10
PAS2	OPEN	11

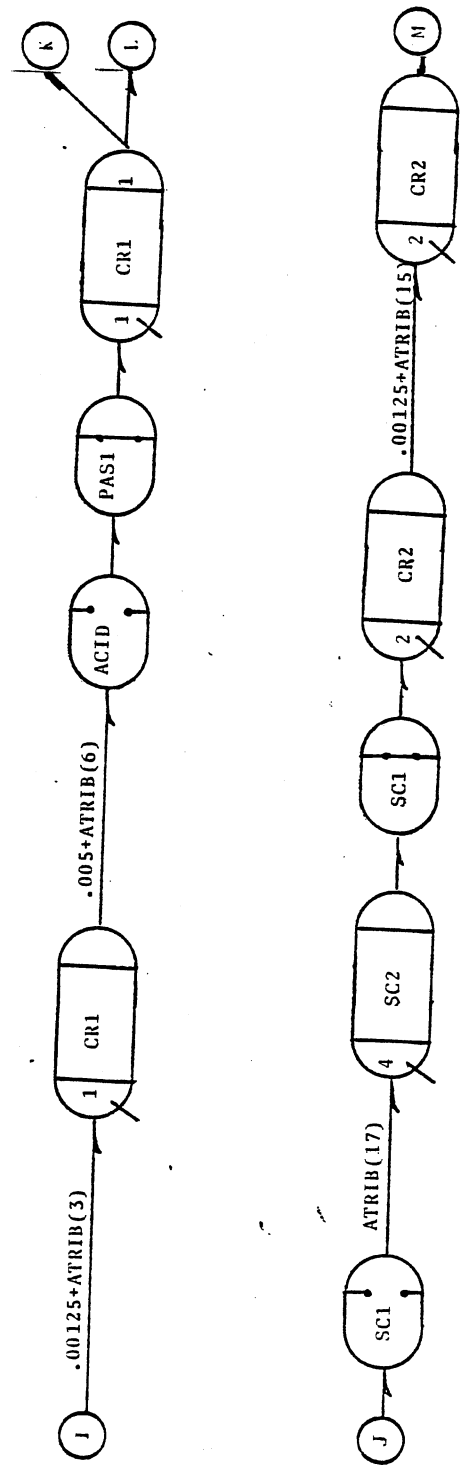

A
ATRIB(6)=RNORM(.012,.0034,5)
ATRIB(7)=2*RNORM(.0145,.0048,6)
ATRIB(8)=RNORM(.0159,.00384,7)
ATRIB(9)=2*RNORM(.0139,.00346,8)
1
ATRIB(10)=EXPON(.1673,9)
ATRIB(25)=TNOW
ATRIB(29)=GAMMA(.42017,3.1829,5)
1
C
B
ATRIB(18)=RNORM(.012,.0034,5)
ATRIB(19)=2*RNORM(.0145,.0048,6)
ATRIB(20)=RNORM(.0159,.00384,7)
ATRIB(21)=2*RNORM(.0139,.00346,8)
1
ATRIB(22)=EXPON(.1673,9)
ATRIB(26)=TNOW
ATRIB(30)=GAMMA(.42017,3.1829,5)
1
D

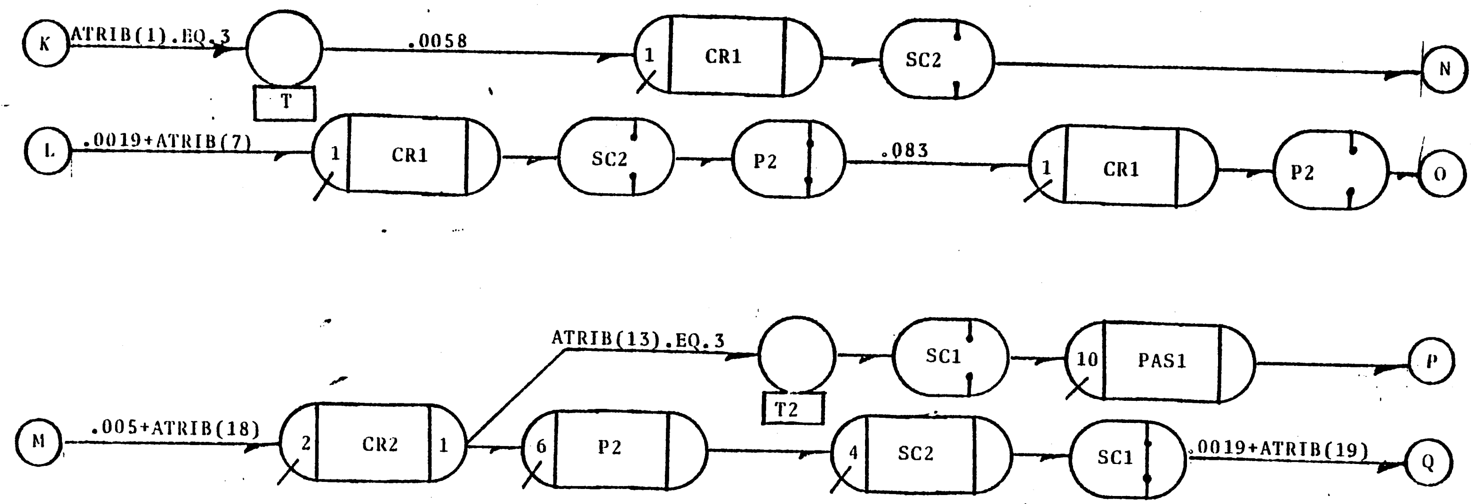

C
8
SC1
SC2
.114+ATRIB(2)
1
CR1
SC2
C2
.083
E
D
4
SC2
SC1
.114
2
CR2
SC1
5
C2
F

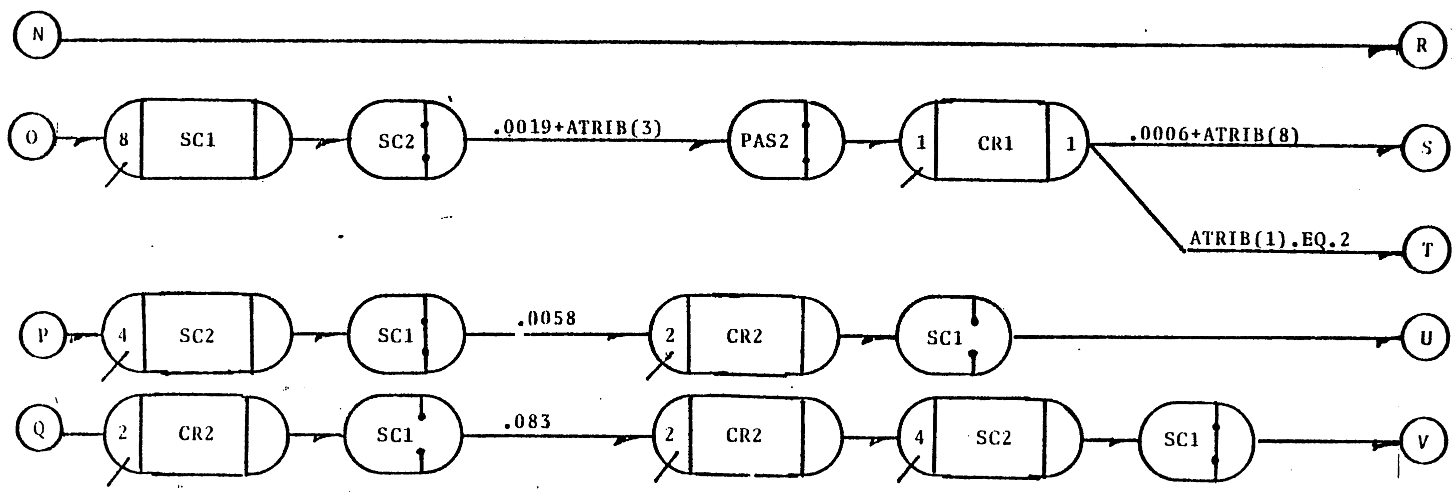


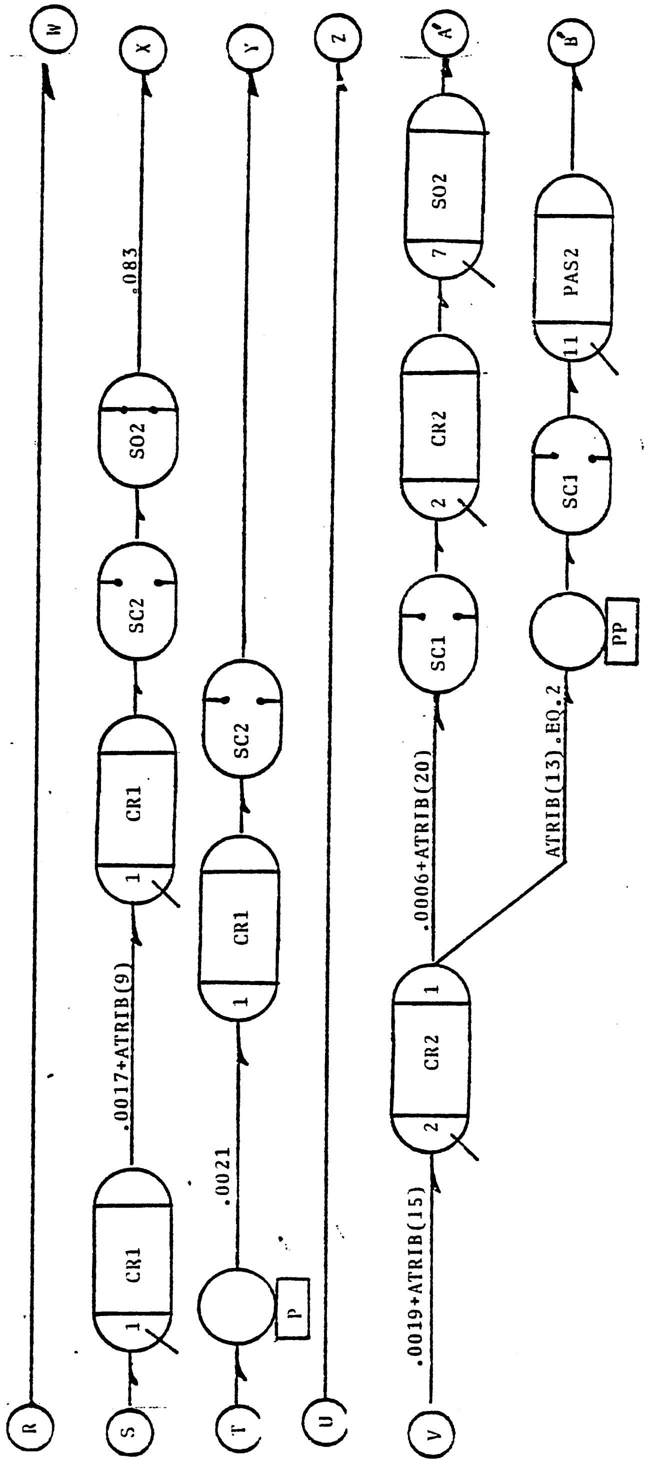
E
1
CR1
8
SC1
SC2
C2
.0008+ATRIB(3)
1
CR1
H
F
4
SC2
SC1
ATRIB(14)
.083
SC1
2
CR2
G


H
.00125+ATRIB(4)
SC2
C2
ATRIB(5)
8
SC1
SC2
1
CR1
I
G
9
ACID
4
SC2
SC1
.00083+ATRIB(15)
2
CR2
.00125+ATRIB(16)
J

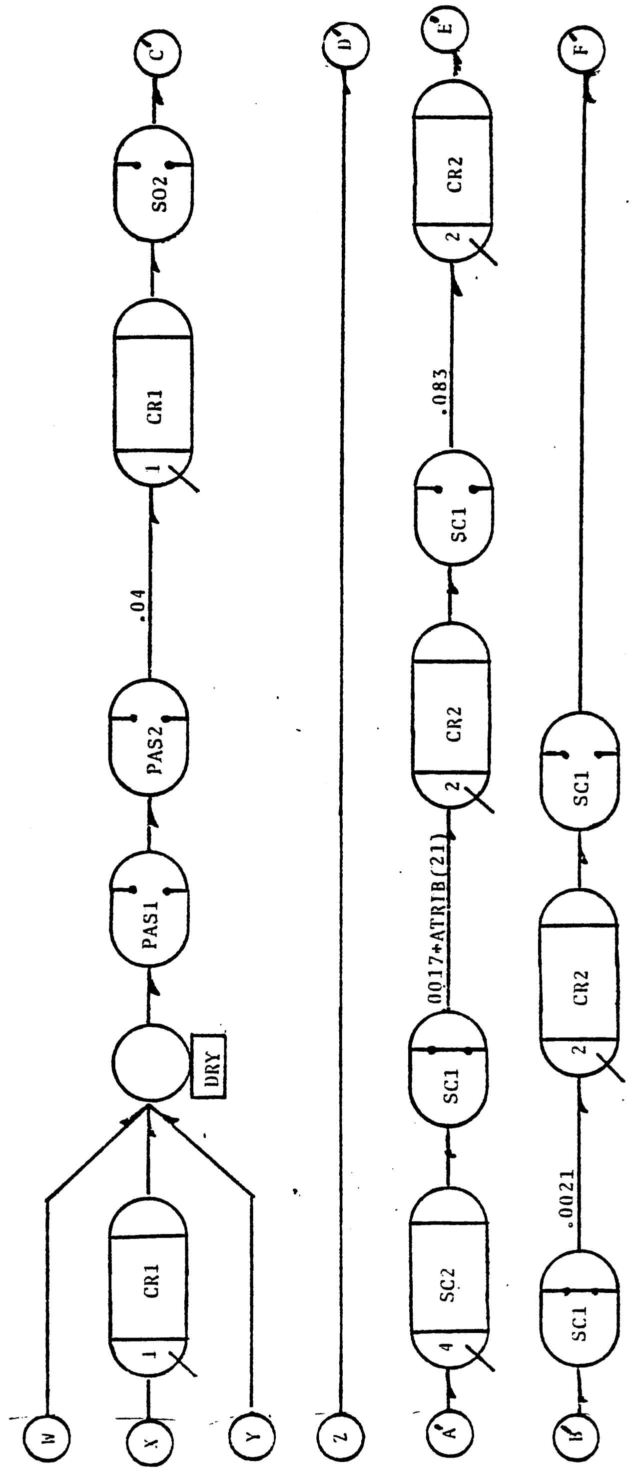

J
.00125+ATRIB(3)
1
CR1
.005+ATRIB(6)
ACID
PAS1
1
CR1
1
K
L
J
SC1
ATRIB(17)
4
SC2
SC1
2
CR2
.00125+ATRIB(15)
2
CR2
M

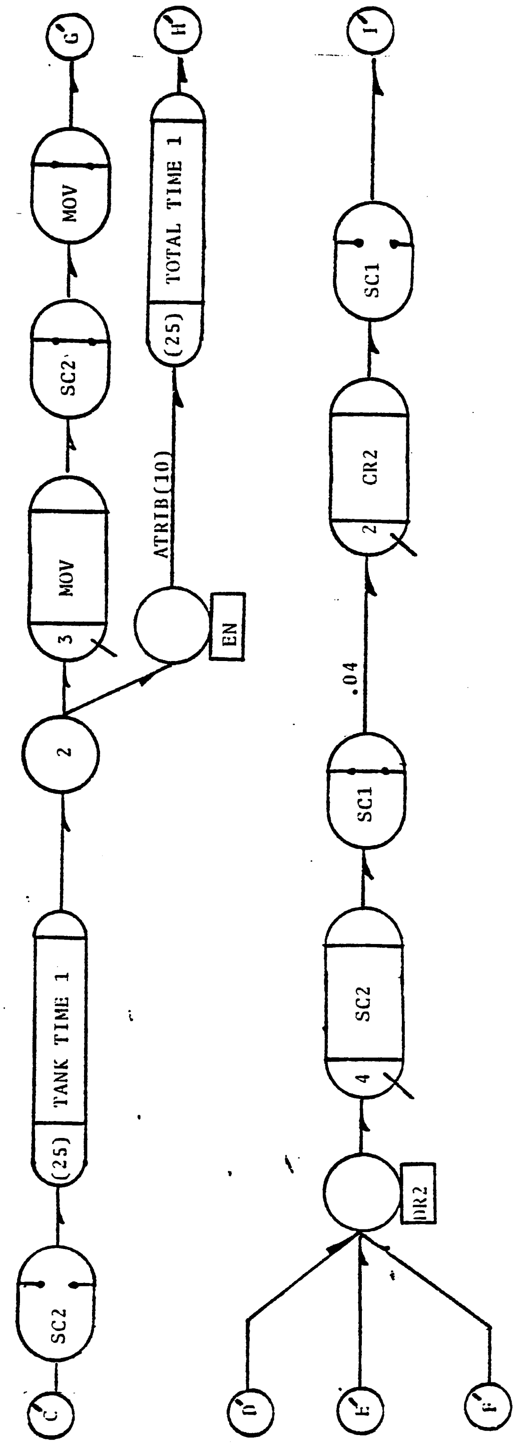

K
ATRIB(1).EQ.3
T
.0058
1
CR1
SC2
N
L
.0019+ATRIB(7)
1
CR1
SC2
P2
.083
1
CR1
P2
O
M
.005+ATRIB(18)
2
CR2
1
ATRIB(13).EQ.3
T2
SC1
10
PAS1
P
6
P2
4
SC2
SC1
.0019+ATRIB(19)
Q

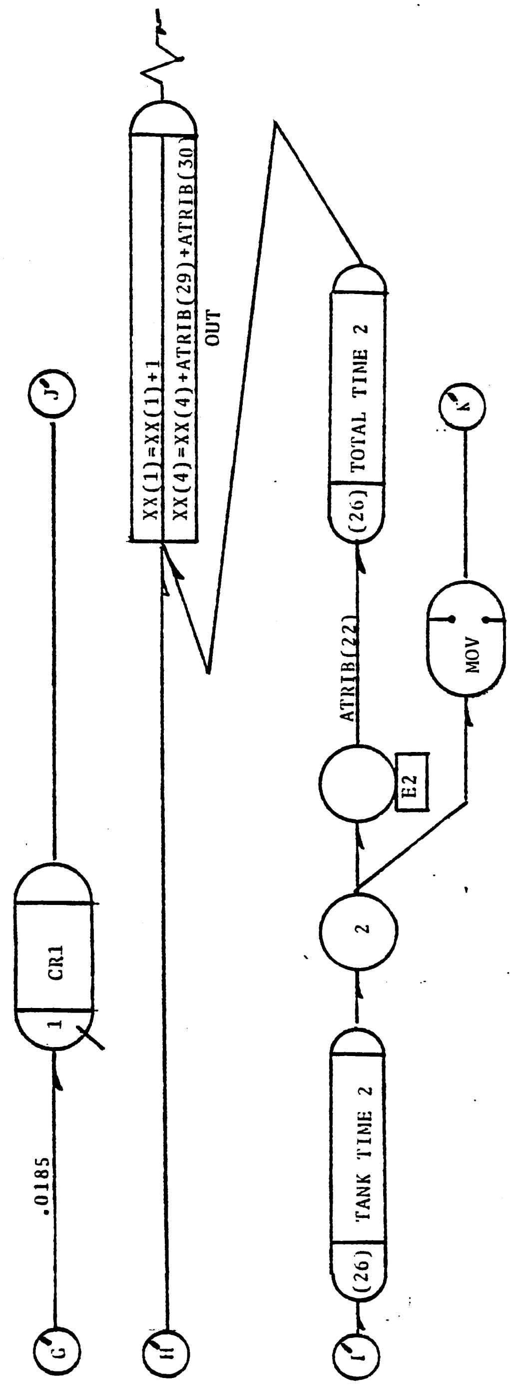

N
R
O
8
SC1
SC2
.0019+ATRIB(3)
PAS2
1
CR1
1
.0006+ATRIB(8)
S
ATRIB(1).EQ.2
T
P
4
SC2
SC1
.0058
2
CR2
SC1
U
Q
2
CR2
SC1
.083
2
CR2
4
SC2
SC1
V

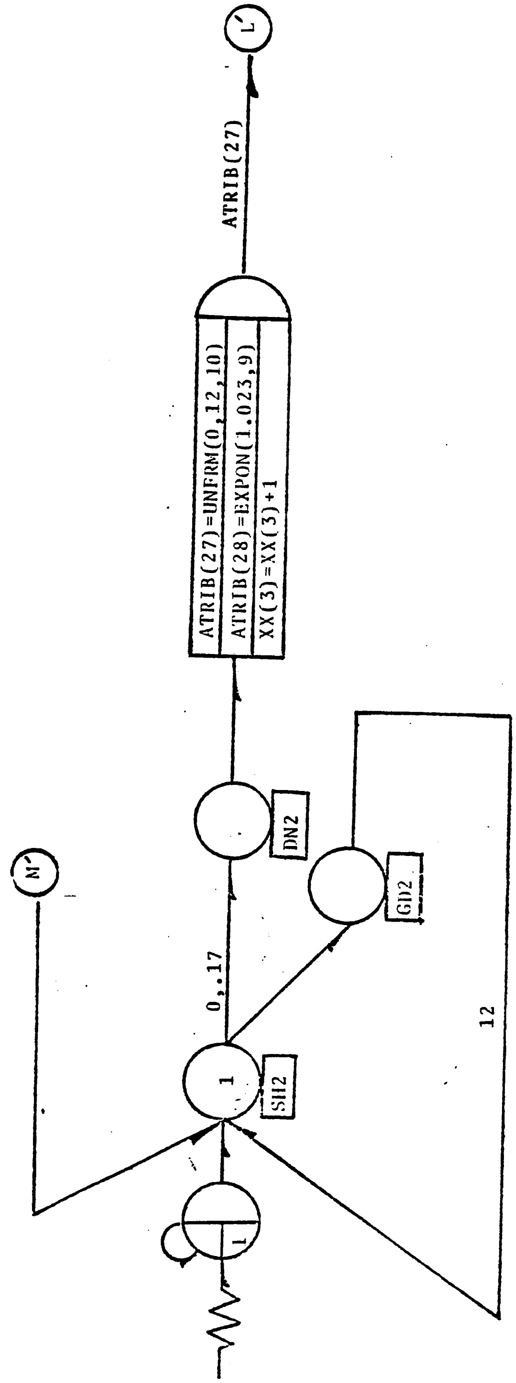


R
S
T
U
V
W
X
Y
Z
A'
B'
CR1
CR1
CR1
CR1
CR2
CR2
SC1
SC1
SC2
SC2
SO2
SO2
PAS2
P
PP
.0017+ATRIB(9)
.083
.0021
.0019+ATRIB(15)
.0006+ATRIB(20)
ATRIB(13).EQ.2
1
2
7
11

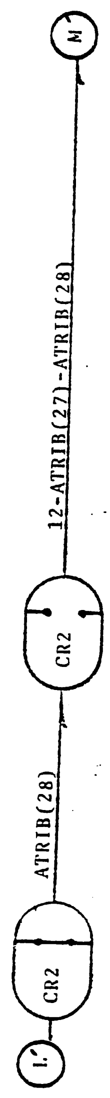

W
X
Y
Z
A'
B'
CR1
1
DRY
PAS1
PAS2
.04
CR1
1
SO2
C'
D'
SC2
4
SC1
.0017+ATRIB(21)
CR2
2
SC1
.083
CR2
2
E'
SC1
.0021
CR2
2
SC1
F'

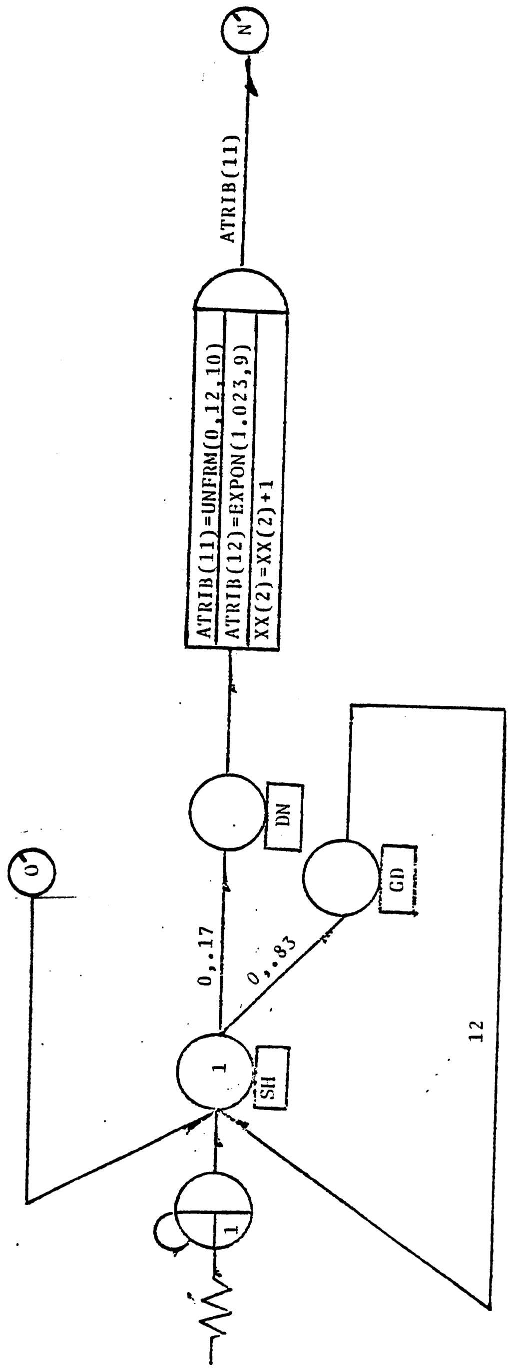

C'
SC2
(25)
TANK TIME 1
2
3
MOV
SC2
G'
EN
ATRIB(10)
TOTAL TIME 1
H'
D'
E'
F'
DR2
4
SC1
.04
CR2
I'

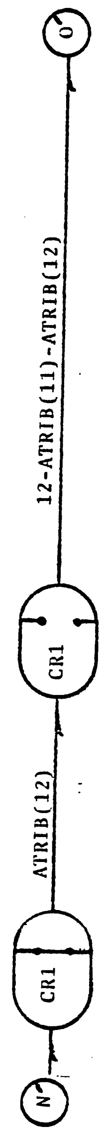

G
.0185
1
CR1
J
H
XX(1)=XX(1)+1
XX(4)=XX(4)+ATRIB(29)+ATRIB(30)
OUT
I
(26)
TANK TIME 2
2
E2
ATRIB(22)
(26)
TOTAL TIME 2
MOV
K



ATRIB(27)
L′
ATRIB(27)=UNFRM(0,12,10)
ATRIB(28)=EXPON(1.023,9)
XX(3)=XX(3)+1
N′
DN2
GD2
0,.17
1
SH2
12
1


L'
CR2
ATRIB(28)
CR2
12-ATRIB(27)-ATRIB(28)
M'


ATRIB(11)=UNFRM(0,12,10)
ATRIB(12)=EXPON(1.023,9)
XX(2)=XX(2)+1
ATRIB(11)
N
O
DN
GD
SH
1
0,.17
0,.83
12
1


O
12-ATRIB(11)-ATRIB(12)
CR1
ATRIB(12)
CR1
N

APPENDIX D

TWO CRANE TWO OPERATOR SLAM ATTRIBUTES,

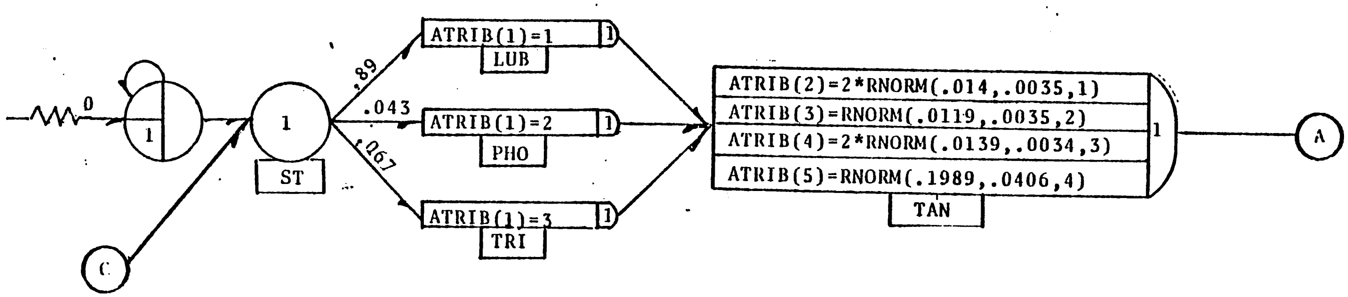
LISTING, AND NETWORK

ATTRIBUTE DESCRIPTION OF TWO CRANE TWO OPERATOR MODEL

Attribute	Description
1	Type of Operation
2	Caustic Dipping
3	Cold Water Dipping
4	Acid Dipping
5	Acid Soak
6	Hot Water Dipping
7	Phosphate Dipping
8	Neutralizer Dipping
9	Soap Dipping
10	Drying
11	Breakdown Time, Crane 1
12	Breakdown Length, Crane 1
13	Time an Entity Starts in the System
14	Breakdown Time, Crane 2
15	Breakdown Length, Crane 2
16	Tons/Trip

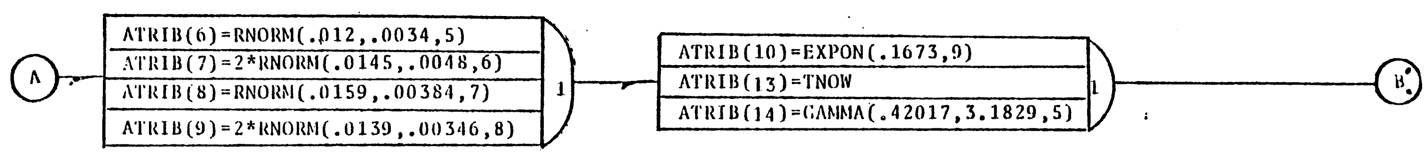
```
GEN,J. R. LEWIS,TANKS,1/04/84,10;
LIMITS,4,16,10;
INIT,0,360;
INTLC,XX(1)=0;
INTLC,XX(2)=0;
INTLC,XX(3)=0;
TIMST,XX(1),NUMBER IN SYS. 1;
TIMST,XX(2),NUMBER OF BRKDWNS.;
TIMST,XX(3),NUMBER OF BRKDOWNS 2;
TIMST,XX(4),TON OUTPUT;
NETWORK;
      RESOURCE/WC1,2;
      RESOURCE/WC2,3;
      GATE/CR1,OPEN,1;
      GATE/CR2,OPEN,4;
      CREATE;
ST    GOON,1;
      ACT,,.89,LUB;
      ACT,,.043,PHO;
      ACT,,.067,TRI;
LUB   ASSIGN,ATRIB(1)=1;
      ACT,,,TAN;
PHO   ASSIGN,ATRIB(1)=2;
      ACT,,,TAN;
TRI   ASSIGN,ATRIB(1)=3;
      ACT,,,TAN;
TAN   ASSIGN,ATRIB(2)=2*RNORM(.014,.0035,1);
      ASSIGN,ATRIB(3)=RNORM(.0119,.0035,2);
      ASSIGN,ATRIB(4)=2*RNORM(.0139,.0034,3);
      ASSIGN,ATRIB(5)=RNORM(.1989,.0406,4);
      ASSIGN,ATRIB(6)=RNORM(.012,.0034,5);
      ASSIGN,ATRIB(7)=2*RNORM(.0145,.0048,6);
      ASSIGN,ATRIB(8)=RNORM(.0159,.00384,7);
      ASSIGN,ATRIB(9)=2*RNORM(.0139,.00346,8);
      ASSIGN,ATRIB(10)=EXPON(.1673,9);
      ASSIGN,ATRIB(13)=TNOW;
      ASSIGN,ATRIB(16)=GAMMA(.42017,3.18293,5);
      ACT;
      GOON;
      ACT,.198+ATRIB(2);                      CAUSTIC DIP AND SOAK
      AWAIT,CR1;
      ACT,.00083+ATRIB(3);                    COLD WATER RINSE
      AWAIT,CR1;
      ACT,.00125+ATRIB(4)+ATRIB(5);           ACID DIP AND SOAK
      AWAIT,CR1;
      ACT,.00125+ATRIB(3);                    COLD WATER RINSE
      AWAIT,CR1;
      AWAIT,WC1;
      ACT,.033;
      GOON,2;
      ACT,.00871,,ST;
      ACT;
      AWAIT,WC2;
      ACT,.033+.005+ATRIB(6);
      FREE,WC1;
      AWAIT,CR2,1;
      ACT,,ATRIB(3).EQ.3,T;
      ACT,.0852+ATRIB(7);                     PHOSPHATE
      AWAIT,CR2;
      ACT,.0019+ATRIB(3);                     COLD WATER RINSE
      AWAIT,CR2,1;
      ACT,,ATRIB(1).EQ.2,P;
```

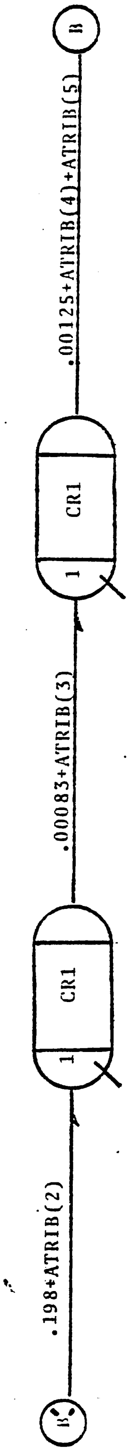
```
        ACT,.0006+ATRIB(8);                      NEUTRALIZER
        AWAIT,CR2;
        ACT,.085+ATRIB(9),,DRY;                  SOAP
T       GOON;
        ACT,.0058,,DRY;                          TRICK
P       GOON;
        ACT,.0021,,DRY;                          PHOSPHATE
DRY     AWAIT,CR2;
        ACT,.04;
        AWAIT,CR2,2;
        ACT,,,EN;
        ACT,.0158;
        AWAIT,CR2;
        COLCT,INT(13),TANK TIME,15/.5/.1;
        ACT,.0158;
        FREE,WC2;
        TERM;
EN      GOON;
        ACT,ATRIB(10);
        COLCT,INT(13),TOTAL TIME,15/.5/.1;
        ASSIGN,XX(1)=XX(1)+1;
        ASSIGN,XX(4)=XX(4)+ATRIB(16);
        TERM;
        CREATE;                          NETWORK TO RUN BREAKDOWNS
SH      GOON,1;
        ACT,,.83,GD;
        ACT,,.17,DN;                     DETERMINE IF BRKDWN OCCURS
GD      GOON;
        ACT,12,,SH;
DN      ASSIGN,ATRIB(11)=UNFRM(0,12,10);
        ASSIGN,ATRIB(12)=EXPON(1.023,9);
        ASSIGN,XX(2)=XX(2)+1,1;
        ACT,ATRIB(11);
        CLOSE,CR1;
        ACT,,ATRIB(11)+ATRIB(12).GT.12,E;
        ACT,ATRIB(12);
        OPEN,CR1;
        ACT,12-ATRIB(11)-ATRIB(12),,SH;
E       GOON;
        OPEN,CR1;
        ACT,,,SH;
        CREATE;                          NETWORK TO RUN BREAKDOWNS
SH2     GOON,1;
        ACT,,.83,GD2;
        ACT,,.17,DN2;                     DETERMINE IF BRKDWN OCCURS
GD2     GOON;
        ACT,12,,SH2;
DN2     ASSIGN,ATRIB(14)=UNFRM(0,12,10);
        ASSIGN,ATRIB(15)=EXPON(1.023,9);
        ASSIGN,XX(3)=XX(3)+1,1;
        ACT,ATRIB(14);
        CLOSE,CR2;
        ACT,,ATRIB(14)+ATRIB(15).GT.12,EE;
        ACT,ATRIB(15);
        OPEN,CR2;
        ACT,12-ATRIB(14)-ATRIB(15),,SH2;
EE      GOON;
        OPEN,CR2;
        ACT,,,SH;
        END;
FIN;
```

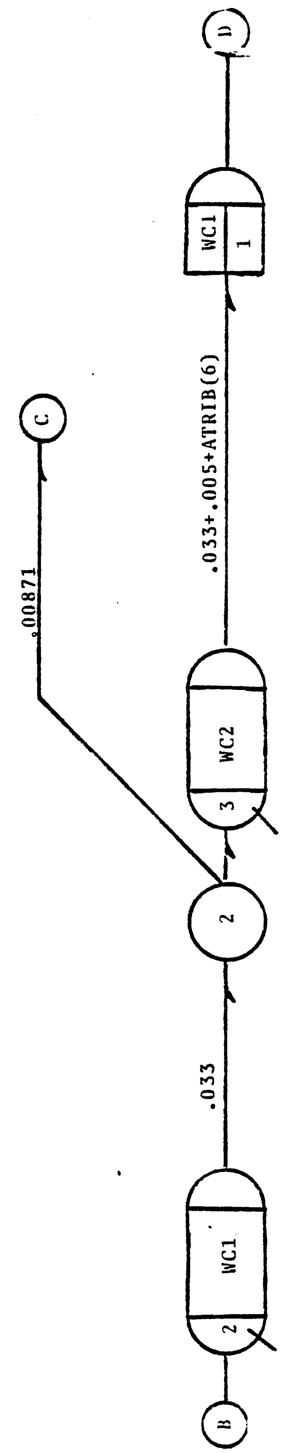


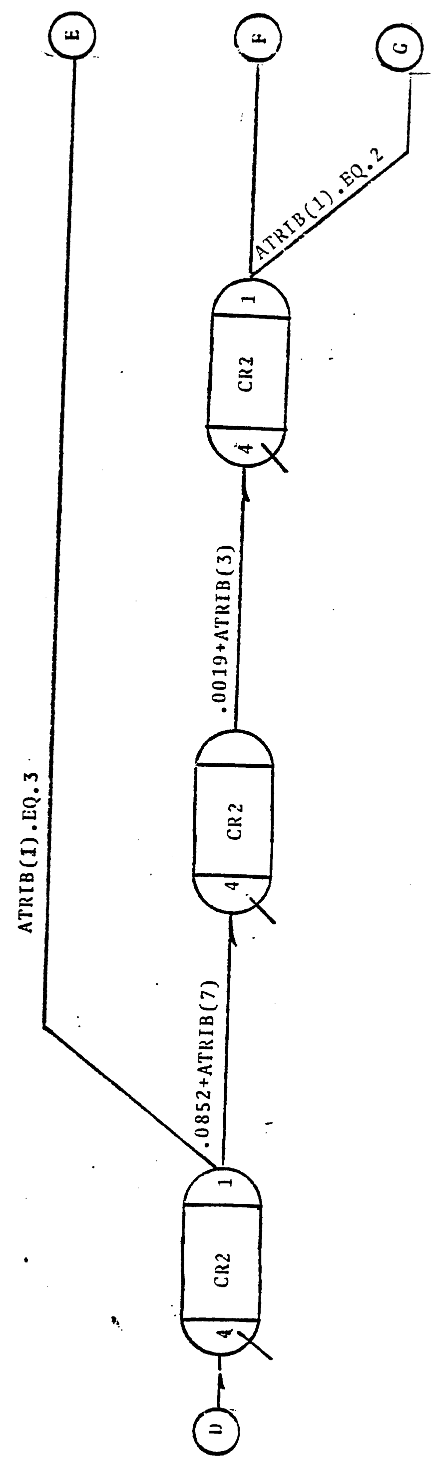
CR1	OPEN	1
CR2	OPEN	4

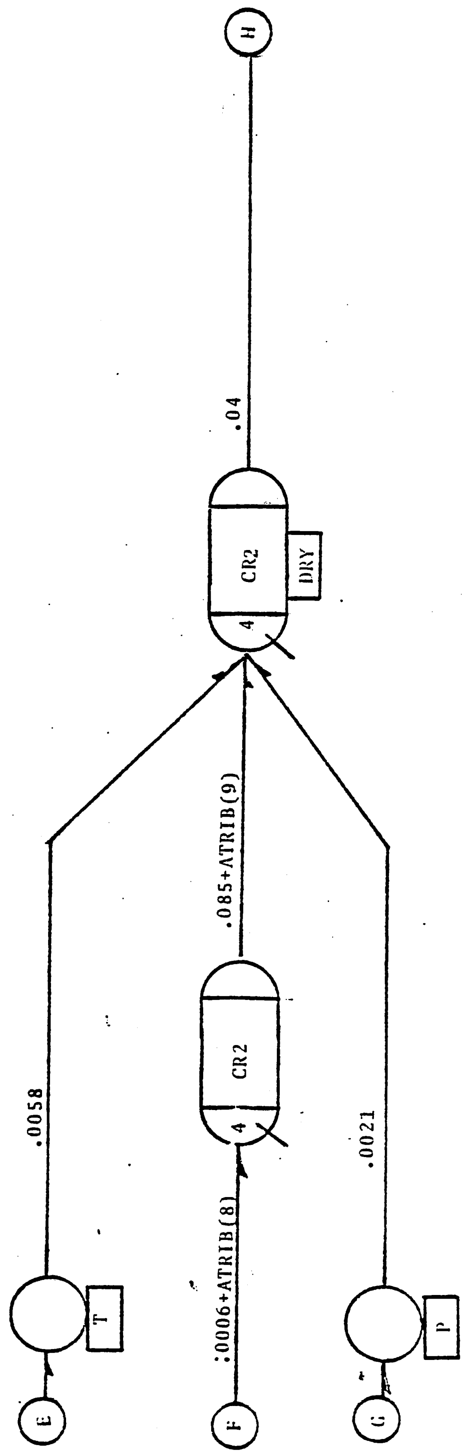
WC1(1)	3
WC2(1)	4

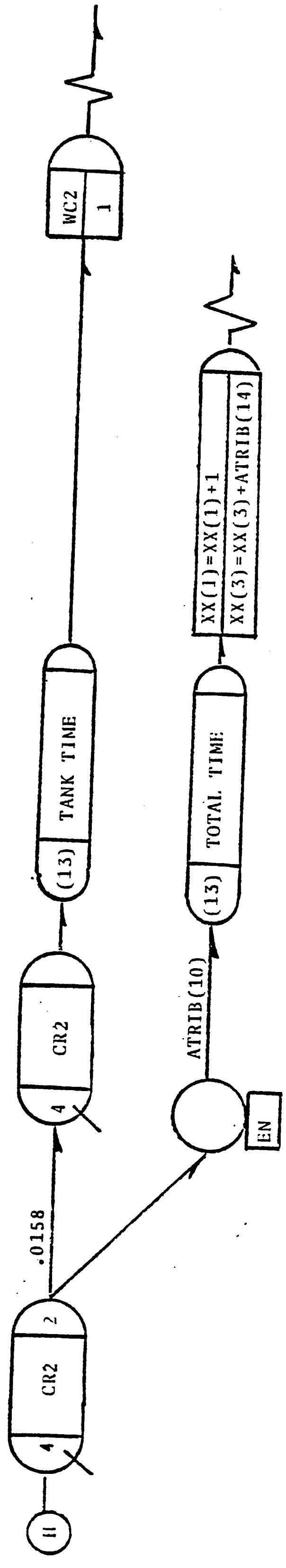

A
ATRIB(6)=RNORM(.012,.0034,5)
ATRIB(7)=2*RNORM(.0145,.0048,6)
ATRIB(8)=RNORM(.0159,.00384,7)
ATRIB(9)=2*RNORM(.0139,.00346,8)
1
ATRIB(10)=EXPON(.1673,9)
ATRIB(13)=TNOW
ATRIB(14)=GAMMA(.42017,3.1829,5)
1
B

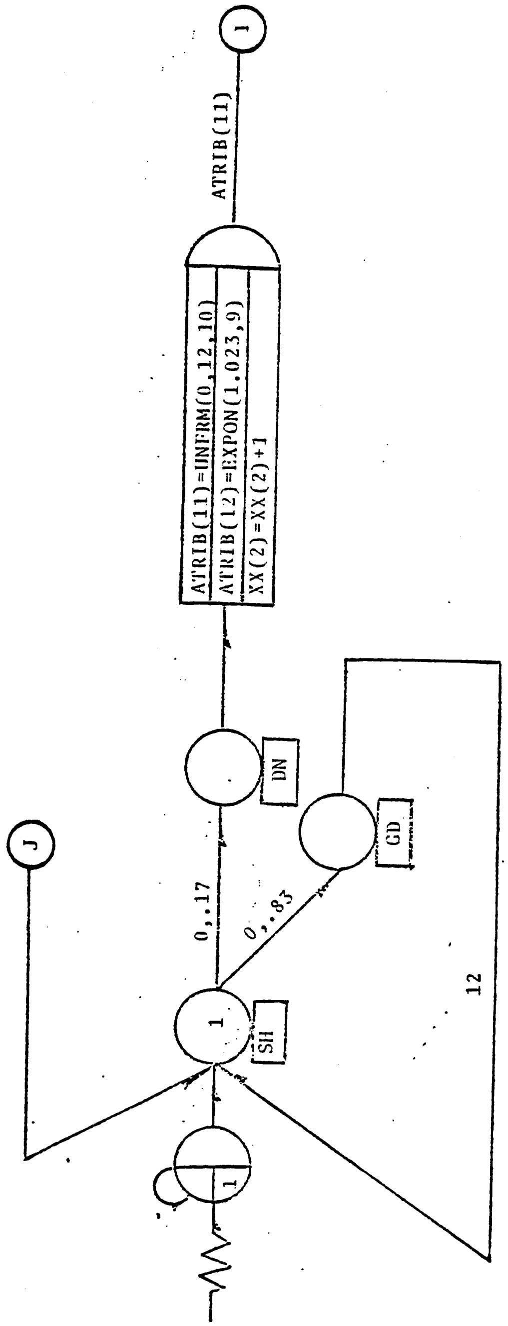

.198+ATRIB(2)
1
CR1
.00083+ATRIB(3)
1
CR1
.00125+ATRIB(4)+ATRIB(5)
B

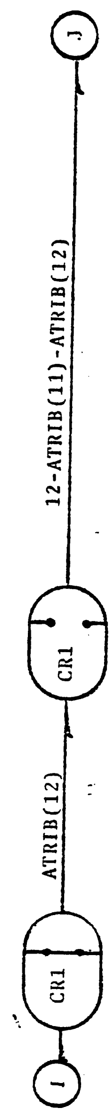

B
WC1
2
.033
2
3
WC2
.00871
C
.033+.005+ATRIB(6)
WC1
1
D

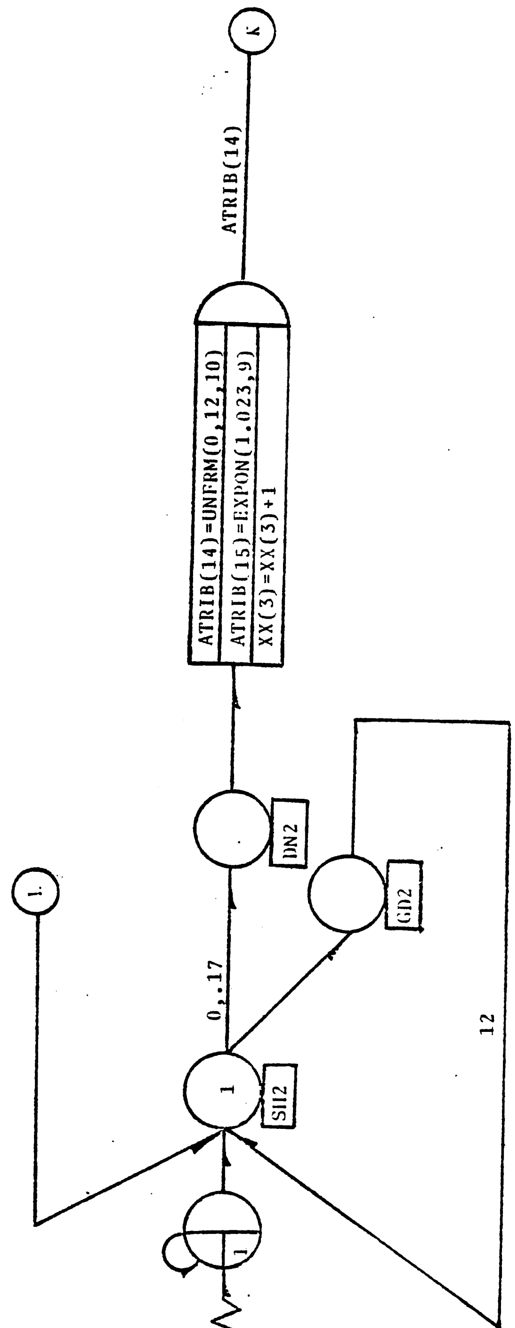

E
F
G
ATRIB(1).EQ.2
1
CR2
4
.0019+ATRIB(3)
CR2
4
ATRIB(1).EQ.3
.0852+ATRIB(7)
1
CR2
4
D

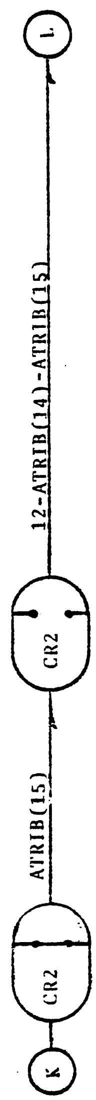

H
.04
CR2
4
DRY
.085+ATRIB(9)
.0058
CR2
4
.0021
T
.0006+ATRIB(8)
P
E
F
G


II
4
CR2
2
.0158
4
CR2
(13)
TANK TIME
WC2
1
ATRIB(10)
EN
(13)
TOTAL TIME
XX(1)=XX(1)+1
XX(3)=XX(3)+ATRIB(14)


1
ATRIB(11)
ATRIB(11)=UNFRM(0,12,10)
ATRIB(12)=EXPON(1.023,9)
XX(2)=XX(2)+1
DN
GD
J
0,.17
0,.83
1
SH
12
1


I
CR1
ATRIB(12)
CR1
12-ATRIB(11)-ATRIB(12)
J


ATRIB(14)=UNFRM(0,12,10)
ATRIB(15)=EXPON(1.023,9)
XX(3)=XX(3)+1
ATRIB(14)
K
DN2
GD2
SH2
1
0,.17
12
L
1


K
CR2
ATRIB(15)
CR2
12-ATRIB(14)-ATRIB(15)
L

APPENDIX E

OUTPUT OF PRESENT SYSTEM MODEL

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

SIMULATION PROJECT TANKS   BY J. R. LEWIS

DATE 1/ 4/1984   RUN NUMBER 1 OF 10

CURRENT TIME 0.3600E+03
STATISTICAL ARRAYS CLEARED AT TIME 0.0000E+00

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
TANK TIME	0.8124E+00	0.6126E-01	0.7541E-01	0.6025E+00	0.1336E+01	443
TOTAL TIME	0.9637E+00	0.1812E+00	0.1880E+00	0.6467E+00	0.2792E+01	442

STATISTICS FOR TIME-PERSISTENT VARIABLES

	MEAN VALUE	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	TIME INTERVAL	CURRENT VALUE
NUMBER IN SYS. 1	0.2209E+03	0.1280E+03	0.0000E+00	0.4420E+03	0.3600E+03	0.4420E+03
NUMBER OF BRKDWN	0.3076E+01	0.1244E+01	0.0000E+00	0.5000E+01	0.3600E+03	0.5000E+01
TON OUTPUT	0.2985E+03	0.1687E+03	0.0000E+00	0.5890E+03	0.3600E+03	0.5890E+03

FILE STATISTICS

FILE NUMBER	ASSOCIATED NODE TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAITING TIME
1	AWAIT	0.0024	0.0490	1	0	0.0002
2		0.0000	0.0000	0	0	0.0000
3	CALENDAR	2.2023	0.4130	4	3	0.1041

GATE STATISTICS

GATE NUMBER	GATE LABEL	CURRENT STATUS	PCT. OF TIME OPEN
1	CR1	OPEN	0.9965

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

SIMULATION PROJECT TANKS   BY J. R. LEWIS

DATE 1/ 4/1984   RUN NUMBER 2 OF 10

CURRENT TIME 0.3600E+03
STATISTICAL ARRAYS CLEARED AT TIME 0.0000E+00

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
TANK TIME	0.8228E+00	0.1782E+00	0.2166E+00	0.6231E+00	0.3733E+01	437
TOTAL TIME	0.9757E+00	0.1959E+00	0.2008E+00	0.7017E+00	0.2656E+01	437

STATISTICS FOR TIME-PERSISTENT VARIABLES

	MEAN VALUE	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	TIME INTERVAL	CURRENT VALUE
NUMBER IN SYS. 1	0.2182E+03	0.1275E+03	0.0000E+00	0.4370E+03	0.3600E+03	0.4370E+03
NUMBER OF BRKDWN	0.1900E+01	0.1012E+01	0.0000E+00	0.4000E+01	0.3600E+03	0.4000E+01
TON OUTPUT	0.2956E+03	0.1746E+03	0.0000E+00	0.5997E+03	0.3600E+03	0.5997E+03

FILE STATISTICS

FILE NUMBER	ASSOCIATED NODE TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAITING TIME
1	AWAIT	0.0172	0.1301	1	0	0.0013
2		0.0000	0.0000	0	0	0.0000
3	CALENDAR	2.1950	0.4422	4	2	0.1051

GATE STATISTICS

GATE NUMBER	GATE LABEL	CURRENT STATUS	PCT. OF TIME OPEN
1	CR1	OPEN	0.9821

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

SIMULATION PROJECT TANKS   BY J. R. LEWIS

DATE 1/ 4/1984   RUN NUMBER 3 OF 10

CURRENT TIME 0.3600E+03
STATISTICAL ARRAYS CLEARED AT TIME 0.0000E+00

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
TANK TIME	0.8303E+00	0.2452E+00	0.2953E+00	0.6283E+00	0.3793E+01	433
TOTAL TIME	0.9622E+00	0.2777E+00	0.2886E+00	0.6746E+00	0.3828E+01	433

STATISTICS FOR TIME-PERSISTENT VARIABLES

	MEAN VALUE	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	TIME INTERVAL	CURRENT VALUE
NUMBER IN SYS. 1	0.2182E+03	0.1247E+03	0.0000E+00	0.4330E+03	0.3600E+03	0.4330E+03
NUMBER OF BRKDWN	0.1933E+01	0.1482E+01	0.0000E+00	0.5000E+01	0.3600E+03	0.5000E+01
TON OUTPUT	0.2752E+03	0.1573E+03	0.0000E+00	0.5576E+03	0.3600E+03	0.5576E+03

FILE STATISTICS

FILE NUMBER	ASSOCIATED NODE TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAITING TIME
1	AWAIT	0.0304	0.1716	1	0	0.0023
2		0.0000	0.0000	0	0	0.0000
3	CALENDAR	2.1467	0.4337	3	2	0.1037

GATE STATISTICS

GATE NUMBER	GATE LABEL	CURRENT STATUS	PCT. OF TIME OPEN
1	CR1	OPEN	0.9687

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

SIMULATION PROJECT TANKS   BY J. R. LEWIS

DATE 1/ 4/1984   RUN NUMBER 4 OF 10

CURRENT TIME 0.3600E+03
STATISTICAL ARRAYS CLEARED AT TIME 0.0000E+00

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
TANK TIME	0.8107E+00	0.1099E+00	0.1356E+00	0.6395E+00	0.2559E+01	444
TOTAL TIME	0.9413E+00	0.1804E+00	0.1916E+00	0.6375E+00	0.2554E+01	443

STATISTICS FOR TIME-PERSISTENT VARIABLES

	MEAN VALUE	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	TIME INTERVAL	CURRENT VALUE
NUMBER IN SYS. 1	0.2223E+03	0.1281E+03	0.0000E+00	0.4430E+03	0.3600E+03	0.4430E+03
NUMBER OF BRKDWN	0.2772E+01	0.2050E+01	0.0000E+00	0.7000E+01	0.3600E+03	0.7000E+01
TON OUTPUT	0.3108E+03	0.1779E+03	0.0000E+00	0.6217E+03	0.3600E+03	0.6217E+03

FILE STATISTICS

FILE NUMBER	ASSOCIATED NODE TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAITING TIME
1	AWAIT	0.0080	0.0888	1	0	0.0006
2		0.0000	0.0000	0	0	0.0000
3	CALENDAR	2.1716	0.4008	4	3	0.1024

GATE STATISTICS

GATE NUMBER	GATE LABEL	CURRENT STATUS	PCT. OF TIME OPEN
1	CR1	OPEN	0.9907

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

SIMULATION PROJECT TANKS　　　　BY J. R. LEWIS

DATE 1/ 4/1984　　　　RUN NUMBER 5 OF 10

CURRENT TIME 0.3600E+03
STATISTICAL ARRAYS CLEARED AT TIME 0.0000E+00

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
TANK TIME	0.8291E+00	0.2331E+00	0.2812E+00	0.6207E+00	0.3886E+01	434
TOTAL TIME	0.9779E+00	0.3025E+00	0.3094E+00	0.6733E+00	0.4074E+01	433

STATISTICS FOR TIME-PERSISTENT VARIABLES

	MEAN VALUE	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	TIME INTERVAL	CURRENT VALUE
NUMBER IN SYS. 1	0.2175E+03	0.1243E+03	0.0000E+00	0.4330E+03	0.3600E+03	0.4330E+03
NUMBER OF BRKDWN	0.3168E+01	0.2698E+01	0.0000E+00	0.7000E+01	0.3600E+03	0.7000E+01
TON OUTPUT	0.2977E+03	0.1740E+03	0.0000E+00	0.5930E+03	0.3600E+03	0.5930E+03

FILE STATISTICS

FILE NUMBER	ASSOCIATED NODE TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAITING TIME
1	AWAIT	0.0270	0.1621	1	0	0.0020
2		0.0000	0.0000	0	0	0.0000
3	CALENDAR	2.1709	0.4469	4	3	0.1046

GATE STATISTICS

GATE NUMBER	GATE LABEL	CURRENT STATUS	PCT. OF TIME OPEN
1	CR1	OPEN	0.9706

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

SIMULATION PROJECT TANKS   BY J. R. LEWIS

DATE 1/ 4/1984   RUN NUMBER   6 OF   10

CURRENT TIME 0.3600E+03
STATISTICAL ARRAYS CLEARED AT TIME 0.0000E+00

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
TANK TIME	0.8154E+00	0.1074E+00	0.1317E+00	0.5873E+00	0.2359E+01	441
TOTAL TIME	0.9669E+00	0.1914E+00	0.1979E+00	0.6018E+00	0.2467E+01	441

STATISTICS FOR TIME-PERSISTENT VARIABLES

	MEAN VALUE	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	TIME INTERVAL	CURRENT VALUE
NUMBER IN SYS. 1	0.2201E+03	0.1272E+03	0.0000E+00	0.4410E+03	0.3600E+03	0.4410E+03
NUMBER OF BRKDWN	0.2567E+01	0.1499E+01	0.0000E+00	0.4000E+01	0.3600E+03	0.4000E+01
TON OUTPUT	0.3111E+03	0.1800E+03	0.0000E+00	0.6165E+03	0.3600E+03	0.6165E+03

FILE STATISTICS

FILE NUMBER	ASSOCIATED NODE TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAITING TIME
1	AWAIT	0.0093	0.0959	1	0	0.0007
2		0.0000	0.0000	0	0	0.0000
3	CALENDAR	2.1950	0.4233	4	2	0.1042

GATE STATISTICS

GATE NUMBER	GATE LABEL	CURRENT STATUS	PCT. OF TIME OPEN
1	CR1	OPEN	0.9900

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

SIMULATION PROJECT TANKS   BY J. R. LEWIS

DATE 1/ 4/1984   RUN NUMBER 7 OF 10

CURRENT TIME 0.3600E+03
STATISTICAL ARRAYS CLEARED AT TIME 0.0000E+00

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
TANK TIME	0.8155E+00	0.1357E+00	0.1664E+00	0.5966E+00	0.3069E+01	441
TOTAL TIME	0.9761E+00	0.2214E+00	0.2268E+00	0.5904E+00	0.3290E+01	441

STATISTICS FOR TIME-PERSISTENT VARIABLES

	MEAN VALUE	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	TIME INTERVAL	CURRENT VALUE
NUMBER IN SYS. 1	0.2211E+03	0.1273E+03	0.0000E+00	0.4410E+03	0.3600E+03	0.4410E+03
NUMBER OF BRKDWN	0.1733E+01	0.1482E+01	0.0000E+00	0.4000E+01	0.3600E+03	0.4000E+01
TON OUTPUT	0.2911E+03	0.1679E+03	0.0000E+00	0.5775E+03	0.3600E+03	0.5775E+03

FILE STATISTICS

FILE NUMBER	ASSOCIATED NODE TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAITING TIME
1	AWAIT	0.0123	0.1102	1	0	0.0009
2		0.0000	0.0000	0	0	0.0000
3	CALENDAR	2.2031	0.4366	4	2	0.1046

GATE STATISTICS

GATE NUMBER	GATE LABEL	CURRENT STATUS	PCT. OF TIME OPEN
1	CR1	OPEN	0.9872

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

SIMULATION PROJECT TANKS BY J. R. LEWIS

DATE 1/ 4/1984 RUN NUMBER 8 OF 10

CURRENT TIME 0.3600E+03
STATISTICAL ARRAYS CLEARED AT TIME 0.0000E+00

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
TANK TIME	0.8239E+00	0.1477E+00	0.1793E+00	0.5925E+00	0.2509E+01	436
TOTAL TIME	0.9714E+00	0.2126E+00	0.2189E+00	0.6758E+00	0.2499E+01	436

STATISTICS FOR TIME-PERSISTENT VARIABLES

	MEAN VALUE	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	TIME INTERVAL	CURRENT VALUE
NUMBER IN SYS. 1	0.2187E+03	0.1262E+03	0.0000E+00	0.4360E+03	0.3600E+03	0.4360E+03
NUMBER OF BRKDWN	0.3300E+01	0.2492E+01	0.0000E+00	0.8000E+01	0.3600E+03	0.8000E+01
TON OUTPUT	0.2971E+03	0.1737E+03	0.0000E+00	0.5938E+03	0.3600E+03	0.5938E+03

FILE STATISTICS

FILE NUMBER	ASSOCIATED NODE TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAITING TIME
1	AWAIT	0.0210	0.1435	1	0	0.0016
2		0.0000	0.0000	0	0	0.0000
3	CALENDAR	2.1761	0.4394	4	2	0.1042

GATE STATISTICS

GATE NUMBER	GATE LABEL	CURRENT STATUS	PCT. OF TIME OPEN
1	CR1	OPEN	0.9773

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

SIMULATION PROJECT TANKS　　　　BY J. R. LEWIS

DATE 1/ 4/1984　　　　RUN NUMBER 9 OF 10

CURRENT TIME 0.3600E+03
STATISTICAL ARRAYS CLEARED AT TIME 0.0000E+00

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
TANK TIME	0.8062E+00	0.5387E-01	0.6682E-01	0.5956E+00	0.9220E+00	446
TOTAL TIME	0.9506E+00	0.1650E+00	0.1735E+00	0.6528E+00	0.1915E+01	446

STATISTICS FOR TIME-PERSISTENT VARIABLES

	MEAN VALUE	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	TIME INTERVAL	CURRENT VALUE
NUMBER IN SYS. 1	0.2225E+03	0.1292E+03	0.0000E+00	0.4460E+03	0.3600E+03	0.4460E+03
NUMBER OF BRKDWN	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.3600E+03	0.0000E+00
TON OUTPUT	0.2849E+03	0.1630E+03	0.0000E+00	0.5713E+03	0.3600E+03	0.5713E+03

FILE STATISTICS

FILE NUMBER	ASSOCIATED NODE TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAITING TIME
1	AWAIT	0.0000	0.0000	0	0	0.0000
2		0.0000	0.0000	0	0	0.0000
3	CALENDAR	2.1977	0.4024	4	2	0.1034

GATE STATISTICS

GATE NUMBER	GATE LABEL	CURRENT STATUS	PCT. OF TIME OPEN
1	CR1	OPEN	1.0000

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

SIMULATION PROJECT TANKS   BY J. R. LEWIS

DATE 1/ 4/1984   RUN NUMBER 10 OF 10

CURRENT TIME 0.3600E+03
STATISTICAL ARRAYS CLEARED AT TIME 0.0000E+00

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
TANK TIME	0.8097E+00	0.7790E-01	0.9621E-01	0.6215E+00	0.1688E+01	444
TOTAL TIME	0.9630E+00	0.1949E+00	0.2024E+00	0.6205E+00	0.2077E+01	444

STATISTICS FOR TIME-PERSISTENT VARIABLES

	MEAN VALUE	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	TIME INTERVAL	CURRENT VALUE
NUMBER IN SYS. 1	0.2213E+03	0.1282E+03	0.0000E+00	0.4440E+03	0.3600E+03	0.4440E+03
NUMBER OF BRKDWN	0.2940E+01	0.2208E+01	0.0000E+00	0.6000E+01	0.3600E+03	0.6000E+01
TON OUTPUT	0.2930E+03	0.1612E+03	0.0000E+00	0.5670E+03	0.3600E+03	0.5670E+03

FILE STATISTICS

FILE NUMBER	ASSOCIATED NODE TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAITING TIME
1	AWAIT	0.0056	0.0746	1	0	0.0004
2		0.0000	0.0000	0	0	0.0000
3	CALENDAR	2.2024	0.4198	4	2	0.1037

GATE STATISTICS

GATE NUMBER	GATE LABEL	CURRENT STATUS	PCT. OF TIME OPEN
1	CR1	OPEN	0.9925

APPENDIX F

OUTPUT OF TWO CRANE ONE OPERATOR MODEL

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

SIMULATION PROJECT TANKS BY J. R. LEWIS

DATE 1/ 4/1984 RUN NUMBER 1 OF 10

CURRENT TIME 0.3600E+03
STATISTICAL ARRAYS CLEARED AT TIME 0.0000E+00

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
TANK TIME SYS 1	0.8981E+00	0.2038E+00	0.2269E+00	0.5122E+00	0.3451E+01	389
TOTAL TIME SYS 1	0.1064E+01	0.2632E+00	0.2473E+00	0.5514E+00	0.3632E+01	389
TANK TIME SYS 2	0.9157E+00	0.2112E+00	0.2307E+00	0.4894E+00	0.3480E+01	393
TOTAL TIME SYS 2	0.1093E+01	0.2792E+00	0.2555E+00	0.5238E+00	0.3942E+01	392

STATISTICS FOR TIME-PERSISTENT VARIABLES

	MEAN VALUE	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	TIME INTERVAL	CURRENT VALUE
NUMBER IN SYS. 1	0.3892E+03	0.2270E+03	0.0000E+00	0.7810E+03	0.3600E+03	0.7810E+03
NUMBER OF BRKDWN	0.1633E+01	0.7063E+00	0.0000E+00	0.3000E+01	0.3600E+03	0.3000E+01
NUMBER OF BRKDWN	0.3933E+01	0.1750E+01	0.0000E+00	0.6000E+01	0.3600E+03	0.6000E+01
TON OUTPUT	0.5217E+03	0.3014E+03	0.0000E+00	0.1046E+04	0.3600E+03	0.1046E+04

FILE STATISTICS

FILE NUMBER	ASSOCIATED NODE TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAITING TIME
1	AWAIT	0.0070	0.0835	1	0	0.0005
2	AWAIT	0.0123	0.1102	1	0	0.0009
3	AWAIT	0.0105	0.1022	1	0	0.0098
4	AWAIT	0.1163	0.3206	1	0	0.0135
5	AWAIT	0.0000	0.0000	1	0	0.0000
6	AWAIT	0.0028	0.0530	1	0	0.0028
7	AWAIT	0.0037	0.0608	1	0	0.0038
8	AWAIT	0.1225	0.3279	1	0	0.0228
9	AWAIT	0.0177	0.1320	1	0	0.0162
10	AWAIT	0.0005	0.0227	1	0	0.0074
11	AWAIT	0.0000	0.0000	0	0	0.0000
12	CALENDAR	4.0777	0.6887	7	5	0.0539

GATE STATISTICS

GATE NUMBER	GATE LABEL	CURRENT STATUS	PCT. OF TIME OPEN
1	CR1	OPEN	0.9919
2	CR2	OPEN	0.9871
3	MOV	OPEN	0.4263
4	SC2	CLOSED	0.6328
5	C2	OPEN	0.8973
6	P2	OPEN	0.9138
7	SO2	OPEN	0.8782
8	SC1	CLOSED	0.5258
9	ACID	OPEN	0.7046
10	PAS1	CLOSED	0.6987
11	PAS2	CLOSED	0.8717

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

SIMULATION PROJECT TANKS   BY J. R. LEWIS

DATE 1/ 4/1984   RUN NUMBER 2 OF 10

CURRENT TIME 0.3600E+03
STATISTICAL ARRAYS CLEARED AT TIME 0.0000E+00

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
TANK TIME SYS 1	0.8956E+00	0.1914E+00	0.2137E+00	0.4717E+00	0.2656E+01	393
TOTAL TIME SYS 1	0.1047E+01	0.2381E+00	0.2274E+00	0.5956E+00	0.2740E+01	393
TANK TIME SYS 2	0.9089E+00	0.2177E+00	0.2395E+00	0.4939E+00	0.3007E+01	396
TOTAL TIME SYS 2	0.1057E+01	0.2599E+00	0.2460E+00	0.5093E+00	0.3063E+01	395

STATISTICS FOR TIME-PERSISTENT VARIABLES

	MEAN VALUE	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	TIME INTERVAL	CURRENT VALUE
NUMBER IN SYS. 1	0.3954E+03	0.2279E+03	0.0000E+00	0.7880E+03	0.3600E+03	0.7880E+03
NUMBER OF BRKDWN	0.5433E+01	0.3052E+01	0.0000E+00	0.1000E+02	0.3600E+03	0.1000E+02
NUMBER OF BRKDWN	0.2733E+01	0.2016E+01	0.0000E+00	0.7000E+01	0.3600E+03	0.7000E+01
TON OUTPUT	0.5239E+03	0.3016E+03	0.0000E+00	0.1059E+04	0.3600E+03	0.1059E+04

FILE STATISTICS

FILE NUMBER	ASSOCIATED NODE TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAITING TIME
1	AWAIT	0.0147	0.1204	1	0	0.0010
2	AWAIT	0.0157	0.1242	1	0	0.0011
3	AWAIT	0.0036	0.0602	1	0	0.0033
4	AWAIT	0.1138	0.3175	1	0	0.0131
5	AWAIT	0.0000	0.0000	1	0	0.0000
6	AWAIT	0.0030	0.0548	1	0	0.0029
7	AWAIT	0.0016	0.0405	1	0	0.0017
8	AWAIT	0.1223	0.3276	1	1	0.0227
9	AWAIT	0.0199	0.1397	1	0	0.0181
10	AWAIT	0.0000	0.0056	1	0	0.0004
11	AWAIT	0.0000	0.0000	0	0	0.0000
12	CALENDAR	4.0312	0.6987	6	4	0.0530

GATE STATISTICS

GATE NUMBER	GATE LABEL	CURRENT STATUS	PCT. OF TIME OPEN
1	CR1	OPEN	0.9835
2	CR2	OPEN	0.9827
3	MOV	OPEN	0.4668
4	SC2	OPEN	0.6376
5	C2	OPEN	0.8976
6	P2	OPEN	0.9132
7	SO2	OPEN	0.8795
8	SC1	CLOSED	0.5208
9	ACID	CLOSED	0.6933
10	PAS1	OPEN	0.6985
11	PAS2	OPEN	0.8729

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SIMULATION PROJECT TANKS   BY J. R. LEWIS

DATE 1/ 4/1984   RUN NUMBER 3 OF 10

CURRENT TIME 0.3600E+03
STATISTICAL ARRAYS CLEARED AT TIME 0.0000E+00

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
TANK TIME SYS 1	0.8982E+00	0.1930E+00	0.2149E+00	0.4824E+00	0.2855E+01	383
TOTAL TIME SYS 1	0.1058E+01	0.2800E+00	0.2647E+00	0.4939E+00	0.3377E+01	383
TANK TIME SYS 2	0.9222E+00	0.2529E+00	0.2743E+00	0.4597E+00	0.2994E+01	390
TOTAL TIME SYS 2	0.1084E+01	0.2958E+00	0.2729E+00	0.6697E+00	0.3184E+01	390

STATISTICS FOR TIME-PERSISTENT VARIABLES

	MEAN VALUE	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	TIME INTERVAL	CURRENT VALUE
NUMBER IN SYS. 1	0.3835E+03	0.2232E+03	0.0000E+00	0.7730E+03	0.3600E+03	0.7730E+03
NUMBER OF BRKDWN	0.2300E+01	0.1345E+01	0.0000E+00	0.4000E+01	0.3600E+03	0.4000E+01
NUMBER OF BRKDWN	0.2633E+01	0.1516E+01	0.0000E+00	0.5000E+01	0.3600E+03	0.5000E+01
TON OUTPUT	0.5284E+03	0.3088E+03	0.0000E+00	0.1068E+04	0.3600E+03	0.1068E+04

FILE STATISTICS

FILE NUMBER	ASSOCIATED NODE TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAITING TIME
1	AWAIT	0.0144	0.1192	1	0	0.0010
2	AWAIT	0.0183	0.1341	1	0	0.0014
3	AWAIT	0.0211	0.1436	1	0	0.0198
4	AWAIT	0.1345	0.3412	1	0	0.0158
5	AWAIT	0.0000	0.0000	1	0	0.0000
6	AWAIT	0.0026	0.0505	1	0	0.0026
7	AWAIT	0.0034	0.0586	1	0	0.0037
8	AWAIT	0.1241	0.3297	1	0	0.0236
9	AWAIT	0.0110	0.1041	1	0	0.0101
10	AWAIT	0.0006	0.0252	1	0	0.0074
11	AWAIT	0.0000	0.0000	0	0	0.0000
12	CALENDAR	4.0135	0.7236	7	4	0.0537

GATE STATISTICS

GATE NUMBER	GATE LABEL	CURRENT STATUS	PCT. OF TIME OPEN
1	CR1	OPEN	0.9853
2	CR2	OPEN	0.9797
3	MOV	OPEN	0.3799
4	SC2	OPEN	0.6242
5	C2	OPEN	0.8951
6	P2	CLOSED	0.9167
7	SO2	OPEN	0.8833
8	SC1	OPEN	0.5366
9	ACID	OPEN	0.7118
10	PAS1	CLOSED	0.7221
11	PAS2	OPEN	0.8769

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SIMULATION PROJECT TANKS   BY J. R. LEWIS

DATE 1/ 4/1984   RUN NUMBER 4 OF 10

CURRENT TIME 0.3600E+03
STATISTICAL ARRAYS CLEARED AT TIME 0.0000E+00

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
TANK TIME SYS 1	0.8898E+00	0.1634E+00	0.1837E+00	0.4939E+00	0.2609E+01	388
TOTAL TIME SYS 1	0.1071E+01	0.2505E+00	0.2339E+00	0.5500E+00	0.2662E+01	388
TANK TIME SYS 2	0.9234E+00	0.1927E+00	0.2087E+00	0.4742E+00	0.2896E+01	389
TOTAL TIME SYS 2	0.1089E+01	0.2515E+00	0.2310E+00	0.5510E+00	0.2956E+01	389

STATISTICS FOR TIME-PERSISTENT VARIABLES

	MEAN VALUE	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	TIME INTERVAL	CURRENT VALUE
NUMBER IN SYS. 1	0.3938E+03	0.2246E+03	0.0000E+00	0.7770E+03	0.3600E+03	0.7770E+03
NUMBER OF BRKDWN	0.2900E+01	0.9781E+00	0.0000E+00	0.4000E+01	0.3600E+03	0.4000E+01
NUMBER OF BRKDWN	0.2267E+01	0.2632E+01	0.0000E+00	0.7000E+01	0.3600E+03	0.7000E+01
TON OUTPUT	0.5345E+03	0.2990E+03	0.0000E+00	0.1040E+04	0.3600E+03	0.1040E+04

FILE STATISTICS

FILE NUMBER	ASSOCIATED NODE TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAITING TIME
1	AWAIT	0.0036	0.0601	1	0	0.0002
2	AWAIT	0.0208	0.1427	1	0	0.0015
3	AWAIT	0.0219	0.1464	1	0	0.0203
4	AWAIT	0.1188	0.3235	1	0	0.0139
5	AWAIT	0.0012	0.0346	1	0	0.0011
6	AWAIT	0.0033	0.0575	1	0	0.0032
7	AWAIT	0.0048	0.0691	1	0	0.0049
8	AWAIT	0.1310	0.3374	1	1	0.0247
9	AWAIT	0.0123	0.1100	1	0	0.0113
10	AWAIT	0.0000	0.0000	0	0	0.0000
11	AWAIT	0.0000	0.0000	0	0	0.0000
12	CALENDAR	4.0544	0.6930	7	3	0.0539

GATE STATISTICS

GATE NUMBER	GATE LABEL	CURRENT STATUS	PCT. OF TIME OPEN
1	CR1	OPEN	0.9951
2	CR2	OPEN	0.9779
3	MOV	CLOSED	0.3754
4	SC2	OPEN	0.6280
5	C2	OPEN	0.8957
6	P2	OPEN	0.9185
7	SO2	OPEN	0.8840
8	SC1	CLOSED	0.5274
9	ACID	OPEN	0.7114
10	PAS1	CLOSED	0.7238
11	PAS2	OPEN	0.8786

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

SIMULATION PROJECT TANKS — BY J. R. LEWIS

DATE 1/ 4/1984 — RUN NUMBER 6 OF 10

CURRENT TIME 0.3600E+03
STATISTICAL ARRAYS CLEARED AT TIME 0.0000E+00

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
TANK TIME SYS 1	0.9031E+00	0.2244E+00	0.2485E+00	0.4776E+00	0.3717E+01	385
TOTAL TIME SYS 1	0.1064E+01	0.2816E+00	0.2647E+00	0.5576E+00	0.4129E+01	385
TANK TIME SYS 2	0.9258E+00	0.2468E+00	0.2665E+00	0.4580E+00	0.3729E+01	388
TOTAL TIME SYS 2	0.1086E+01	0.2902E+00	0.2671E+00	0.4875E+00	0.3774E+01	388

STATISTICS FOR TIME-PERSISTENT VARIABLES

	MEAN VALUE	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	TIME INTERVAL	CURRENT VALUE
NUMBER IN SYS. 1	0.3854E+03	0.2232E+03	0.0000E+00	0.7730E+03	0.3600E+03	0.7730E+03
NUMBER OF BRKDWN	0.2700E+01	0.1509E+01	0.0000E+00	0.5000E+01	0.3600E+03	0.5000E+01
NUMBER OF BRKDWN	0.4322E+01	0.3412E+01	0.0000E+00	0.9000E+01	0.3600E+03	0.9000E+01
TON OUTPUT	0.5036E+03	0.2848E+03	0.0000E+00	0.1020E+04	0.3600E+03	0.1020E+04

FILE STATISTICS

FILE NUMBER	ASSOCIATED NODE TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAITING TIME
1	AWAIT	0.0162	0.1263	1	0	0.0011
2	AWAIT	0.0173	0.1302	1	0	0.0013
3	AWAIT	0.0140	0.1177	1	0	0.0131
4	AWAIT	0.1190	0.3238	1	0	0.0140
5	AWAIT	0.0051	0.0712	1	0	0.0047
6	AWAIT	0.0023	0.0477	1	0	0.0023
7	AWAIT	0.0108	0.1034	1	0	0.0113
8	AWAIT	0.1268	0.3328	1	0	0.0240
9	AWAIT	0.0127	0.1120	1	0	0.0118
10	AWAIT	0.0011	0.0336	1	0	0.0146
11	AWAIT	0.0000	0.0000	0	0	0.0000
12	CALENDAR	4.0177	0.7123	7	4	0.0537

GATE STATISTICS

GATE NUMBER	GATE LABEL	CURRENT STATUS	PCT. OF TIME OPEN
1	CR1	OPEN	0.9832
2	CR2	OPEN	0.9804
3	MOV	CLOSED	0.4159
4	SC2	CLOSED	0.6401
5	C2	OPEN	0.8875
6	P2	OPEN	0.9164
7	SO2	OPEN	0.8716
8	SC1	OPEN	0.5342
9	ACID	CLOSED	0.7178
10	PAS1	OPEN	0.7082
11	PAS2	OPEN	0.8659

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

SIMULATION PROJECT TANKS BY J. R. LEWIS

DATE 1/ 4/1984 RUN NUMBER 7 OF 10

CURRENT TIME 0.3600E+03
STATISTICAL ARRAYS CLEARED AT TIME 0.0000E+00

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
TANK TIME SYS 1	0.9090E+00	0.3077E+00	0.3385E+00	0.4865E+00	0.5284E+01	383
TOTAL TIME SYS 1	0.1074E+01	0.3403E+00	0.3169E+00	0.4987E+00	0.5303E+01	383
TANK TIME SYS 2	0.9322E+00	0.3016E+00	0.3235E+00	0.4863E+00	0.5009E+01	386
TOTAL TIME SYS 2	0.1104E+01	0.3558E+00	0.3223E+00	0.5235E+00	0.5400E+01	386

STATISTICS FOR TIME-PERSISTENT VARIABLES

	MEAN VALUE	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	TIME INTERVAL	CURRENT VALUE
NUMBER IN SYS. 1	0.3805E+03	0.2200E+03	0.0000E+00	0.7690E+03	0.3600E+03	0.7690E+03
NUMBER OF BRKDWN	0.5823E+01	0.2257E+01	0.0000E+00	0.9000E+01	0.3600E+03	0.9000E+01
NUMBER OF BRKDWN	0.1767E+01	0.1202E+01	0.0000E+00	0.3000E+01	0.3600E+03	0.3000E+01
TON OUTPUT	0.5384E+03	0.3112E+03	0.0000E+00	0.1083E+04	0.3600E+03	0.1083E+04

FILE STATISTICS

FILE NUMBER	ASSOCIATED NODE TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAITING TIME
1	AWAIT	0.0283	0.1659	1	0	0.0020
2	AWAIT	0.0118	0.1079	1	0	0.0009
3	AWAIT	0.0127	0.1121	1	0	0.0120
4	AWAIT	0.1221	0.3274	1	0	0.0144
5	AWAIT	0.0156	0.1241	1	0	0.0146
6	AWAIT	0.0061	0.0776	1	0	0.0060
7	AWAIT	0.0041	0.0636	1	0	0.0042
8	AWAIT	0.1238	0.3293	1	0	0.0236
9	AWAIT	0.0130	0.1133	1	0	0.0121
10	AWAIT	0.0007	0.0258	1	0	0.0109
11	AWAIT	0.0000	0.0000	0	0	0.0000
12	CALENDAR	4.0194	0.7330	7	4	0.0540

GATE STATISTICS

GATE NUMBER	GATE LABEL	CURRENT STATUS	PCT. OF TIME OPEN
1	CR1	OPEN	0.9705
2	CR2	OPEN	0.9878
3	MOV	OPEN	0.4217
4	SC2	OPEN	0.6324
5	C2	OPEN	0.8824
6	P2	OPEN	0.9135
7	SO2	CLOSED	0.8843
8	SC1	CLOSED	0.5312
9	ACID	OPEN	0.7138
10	PAS1	CLOSED	0.7176
11	PAS2	CLOSED	0.8741

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

SIMULATION PROJECT TANKS BY J. R. LEWIS

DATE 1/ 4/1984 RUN NUMBER 8 OF 10

CURRENT TIME 0.3600E+03
STATISTICAL ARRAYS CLEARED AT TIME 0.0000E+00

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
TANK TIME SYS 1	0.8813E+00	0.1414E+00	0.1604E+00	0.4098E+00	0.2575E+01	396
TOTAL TIME SYS 1	0.1050E+01	0.2107E+00	0.2007E+00	0.4964E+00	0.2607E+01	396
TANK TIME SYS 2	0.8973E+00	0.1478E+00	0.1647E+00	0.5352E+00	0.2565E+01	401
TOTAL TIME SYS 2	0.1070E+01	0.2271E+00	0.2123E+00	0.5713E+00	0.2621E+01	401

STATISTICS FOR TIME-PERSISTENT VARIABLES

	MEAN VALUE	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	TIME INTERVAL	CURRENT VALUE
NUMBER IN SYS. 1	0.3971E+03	0.2310E+03	0.0000E+00	0.7970E+03	0.3600E+03	0.7970E+03
NUMBER OF BRKDWN	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.3600E+03	0.0000E+00
NUMBER OF BRKDWN	0.2123E+01	0.1303E+01	0.0000E+00	0.5000E+01	0.3600E+03	0.5000E+01
TON OUTPUT	0.5368E+03	0.3210E+03	0.0000E+00	0.1111E+04	0.3600E+03	0.1111E+04

FILE STATISTICS

FILE NUMBER	ASSOCIATED NODE TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAITING TIME
1	AWAIT	0.0000	0.0000	0	0	0.0000
2	AWAIT	0.0095	0.0970	1	0	0.0007
3	AWAIT	0.0119	0.1083	1	0	0.0108
4	AWAIT	0.1140	0.3179	1	0	0.0130
5	AWAIT	0.0000	0.0000	1	0	0.0000
6	AWAIT	0.0017	0.0417	1	0	0.0017
7	AWAIT	0.0024	0.0487	1	0	0.0024
8	AWAIT	0.1248	0.3305	1	0	0.0231
9	AWAIT	0.0150	0.1214	1	0	0.0134
10	AWAIT	0.0000	0.0000	0	0	0.0000
11	AWAIT	0.0002	0.0131	1	0	0.0029
12	CALENDAR	4.0959	0.6648	7	4	0.0534

GATE STATISTICS

GATE NUMBER	GATE LABEL	CURRENT STATUS	PCT. OF TIME OPEN
1	CR1	OPEN	1.0000
2	CR2	OPEN	0.9891
3	MOV	OPEN	0.4203
4	SC2	OPEN	0.6364
5	C2	OPEN	0.8952
6	P2	OPEN	0.9173
7	SO2	OPEN	0.8819
8	SC1	CLOSED	0.5233
9	ACID	CLOSED	0.6997
10	PAS1	OPEN	0.7228
11	PAS2	OPEN	0.8755

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

SIMULATION PROJECT TANKS

BY J. R. LEWIS

DATE 1/ 4/1984

RUN NUMBER 9 OF 10

CURRENT TIME 0.3600E+03
STATISTICAL ARRAYS CLEARED AT TIME 0.0000E+00

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
TANK TIME SYS 1	0.8891E+00	0.1561E+00	0.1755E+00	0.4810E+00	0.2874E+01	386
TOTAL TIME SYS 1	0.1049E+01	0.2132E+00	0.2033E+00	0.5877E+00	0.2965E+01	386
TANK TIME SYS 2	0.9225E+00	0.3141E+00	0.3404E+00	0.4619E+00	0.5947E+01	390
TOTAL TIME SYS 2	0.1089E+01	0.3523E+00	0.3234E+00	0.5431E+00	0.6240E+01	390

STATISTICS FOR TIME-PERSISTENT VARIABLES

	MEAN VALUE	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	TIME INTERVAL	CURRENT VALUE
NUMBER IN SYS. 1	0.3849E+03	0.2238E+03	0.0000E+00	0.7760E+03	0.3600E+03	0.7760E+03
NUMBER OF BRKDWN	0.3000E+01	0.1826E+01	0.0000E+00	0.5000E+01	0.3600E+03	0.5000E+01
NUMBER OF BRKDWN	0.3695E+01	0.1888E+01	0.0000E+00	0.7000E+01	0.3600E+03	0.7000E+01
TON OUTPUT	0.5220E+03	0.3032E+03	0.0000E+00	0.1053E+04	0.3600E+03	0.1053E+04

FILE STATISTICS

FILE NUMBER	ASSOCIATED NODE TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAITING TIME
1	AWAIT	0.0037	0.0606	1	0	0.0003
2	AWAIT	0.0285	0.1663	1	0	0.0021
3	AWAIT	0.0283	0.1657	1	0	0.0264
4	AWAIT	0.1204	0.3254	1	0	0.0141
5	AWAIT	0.0000	0.0000	1	0	0.0000
6	AWAIT	0.0030	0.0551	1	0	0.0030
7	AWAIT	0.0061	0.0776	1	0	0.0064
8	AWAIT	0.1224	0.3278	1	0	0.0231
9	AWAIT	0.0138	0.1165	1	1	0.0127
10	AWAIT	0.0007	0.0265	1	0	0.0097
11	AWAIT	0.0000	0.0000	0	0	0.0000
12	CALENDAR	4.0236	0.7076	7	3	0.0535

GATE STATISTICS

GATE NUMBER	GATE LABEL	CURRENT STATUS	PCT. OF TIME OPEN
1	CR1	OPEN	0.9921
2	CR2	OPEN	0.9707
3	MOV	OPEN	0.4076
4	SC2	OPEN	0.6367
5	C2	OPEN	0.9002
6	P2	OPEN	0.9162
7	SO2	OPEN	0.8782
8	SC1	CLOSED	0.5330
9	ACID	CLOSED	0.7145
10	PAS1	OPEN	0.7123
11	PAS2	OPEN	0.8733

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

SIMULATION PROJECT TANKS BY J. R. LEWIS

DATE 1/ 4/1984 RUN NUMBER 10 OF 10

CURRENT TIME 0.3600E+03
STATISTICAL ARRAYS CLEARED AT TIME 0.0000E+00

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
TANK TIME SYS 1	0.8905E+00	0.1146E+00	0.1287E+00	0.4781E+00	0.1874E+01	391
TOTAL TIME SYS 1	0.1058E+01	0.2048E+00	0.1935E+00	0.5300E+00	0.2293E+01	391
TANK TIME SYS 2	0.9102E+00	0.1424E+00	0.1565E+00	0.4736E+00	0.2043E+01	395
TOTAL TIME SYS 2	0.1089E+01	0.2209E+00	0.2027E+00	0.4744E+00	0.2125E+01	395

STATISTICS FOR TIME-PERSISTENT VARIABLES

	MEAN VALUE	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	TIME INTERVAL	CURRENT VALUE
NUMBER IN SYS. 1	0.3930E+03	0.2280E+03	0.0000E+00	0.7860E+03	0.3600E+03	0.7860E+03
NUMBER OF BRKDWN	0.1400E+01	0.1541E+01	0.0000E+00	0.5000E+01	0.3600E+03	0.5000E+01
NUMBER OF BRKDWN	0.3200E+01	0.1447E+01	0.0000E+00	0.5000E+01	0.3600E+03	0.5000E+01
TON OUTPUT	0.5205E+03	0.3026E+03	0.0000E+00	0.1033E+04	0.3600E+03	0.1033E+04

FILE STATISTICS

FILE NUMBER	ASSOCIATED NODE TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAITING TIME
1	AWAIT	0.0048	0.0692	1	0	0.0003
2	AWAIT	0.0055	0.0742	1	0	0.0004
3	AWAIT	0.0157	0.1243	1	0	0.0145
4	AWAIT	0.1271	0.3331	1	1	0.0147
5	AWAIT	0.0000	0.0000	1	0	0.0000
6	AWAIT	0.0029	0.0540	1	0	0.0028
7	AWAIT	0.0065	0.0802	1	0	0.0066
8	AWAIT	0.1226	0.3280	1	0	0.0229
9	AWAIT	0.0108	0.1035	1	0	0.0098
10	AWAIT	0.0006	0.0245	1	0	0.0099
11	AWAIT	0.0001	0.0121	1	0	0.0029
12	CALENDAR	4.0801	0.6568	7	3	0.0536

GATE STATISTICS

GATE NUMBER	GATE LABEL	CURRENT STATUS	PCT. OF TIME OPEN
1	CR1	OPEN	0.9947
2	CR2	OPEN	0.9943
3	MOV	CLOSED	0.3780
4	SC2	CLOSED	0.6274
5	C2	OPEN	0.9015
6	P2	OPEN	0.9161
7	SO2	OPEN	0.8765
8	SC1	OPEN	0.5308
9	ACID	OPEN	0.7086
10	PAS1	OPEN	0.7126
11	PAS2	OPEN	0.8692

APPENDIX G

OUTPUT OF TWO CRANE TWO OPERATOR MODEL

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

SIMULATION PROJECT TANKS   BY J. R. LEWIS

DATE 1/ 4/1984   RUN NUMBER 1 OF 10

CURRENT TIME 0.3600E+03
STATISTICAL ARRAYS CLEARED AT TIME 0.0000E+00

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
TANK TIME	0.9073E+00	0.1893E+00	0.2087E+00	0.6633E+00	0.2458E+01	668
TOTAL TIME	0.1063E+01	0.2507E+00	0.2359E+00	0.7410E+00	0.2771E+01	667

STATISTICS FOR TIME-PERSISTENT VARIABLES

	MEAN VALUE	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	TIME INTERVAL	CURRENT VALUE
NUMBER IN SYS. 1	0.3349E+03	0.1930E+03	0.0000E+00	0.6670E+03	0.3600E+03	0.6670E+03
NUMBER OF BRKDWN	0.6320E+01	0.2823E+01	0.0000E+00	0.1200E+02	0.3600E+03	0.1200E+02
NUMBER OF BRKDOW	0.4095E+01	0.2533E+01	0.0000E+00	0.9000E+01	0.3600E+03	0.9000E+01
TON OUTPUT	0.4490E+03	0.2551E+03	0.0000E+00	0.8937E+03	0.3600E+03	0.8937E+03

FILE STATISTICS

FILE NUMBER	ASSOCIATED NODE TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAITING TIME
1	AWAIT	0.0195	0.1384	1	0	0.0026
2	AWAIT	0.0072	0.0847	1	0	0.0039
3	AWAIT	0.0199	0.1397	1	0	0.0107
4	AWAIT	0.0163	0.1266	1	0	0.0013
5	CALENDAR	5.8586	0.7462	8	7	0.1288

RESOURCE STATISTICS

RESOURCE NUMBER	RESOURCE LABEL	CURRENT CAPACITY	AVERAGE UTILIZATION	STANDARD DEVIATION	MAXIMUM UTILIZATION	CURRENT UTILIZATION
1	WC1	1	0.1736	0.3787	1	0
2	WC2	1	0.7113	0.4532	1	1

RESOURCE NUMBER	RESOURCE LABEL	CURRENT AVAILABLE	AVERAGE AVAILABLE	MINIMUM AVAILABLE	MAXIMUM AVAILABLE
1	WC1	1	0.8264	0	1
2	WC2	0	0.2887	0	1

GATE STATISTICS

GATE NUMBER	GATE LABEL	CURRENT STATUS	PCT. OF TIME OPEN
1	CR1	OPEN	0.9775
2	CR2	OPEN	0.9829

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

SIMULATION PROJECT TANKS   BY J. R. LEWIS

DATE 1/ 4/1984   RUN NUMBER 2 OF 10

CURRENT TIME 0.3600E+03
STATISTICAL ARRAYS CLEARED AT TIME 0.0000E+00

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
TANK TIME	0.8901E+00	0.1422E+00	0.1598E+00	0.6964E+00	0.2516E+01	678
TOTAL TIME	0.1030E+01	0.1961E+00	0.1904E+00	0.7128E+00	0.2557E+01	678

STATISTICS FOR TIME-PERSISTENT VARIABLES

	MEAN VALUE	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	TIME INTERVAL	CURRENT VALUE
NUMBER IN SYS. 1	0.3365E+03	0.1957E+03	0.0000E+00	0.6780E+03	0.3600E+03	0.6780E+03
NUMBER OF BRKDWN	0.3000E+01	0.1549E+01	0.0000E+00	0.5000E+01	0.3600E+03	0.5000E+01
NUMBER OF BRKDOW	0.2433E+01	0.1687E+01	0.0000E+00	0.4000E+01	0.3600E+03	0.4000E+01
TON OUTPUT	0.4464E+03	0.2549E+03	0.0000E+00	0.9008E+03	0.3600E+03	0.9008E+03

FILE STATISTICS

FILE NUMBER	ASSOCIATED NODE TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAITING TIME
1	AWAIT	0.0097	0.0982	1	0	0.0013
2	AWAIT	0.0037	0.0608	1	0	0.0020
3	AWAIT	0.0119	0.1085	1	0	0.0063
4	AWAIT	0.0103	0.1009	1	0	0.0008
5	CALENDAR	3.9816	0.5857	6	4	0.0871

RESOURCE STATISTICS

RESOURCE NUMBER	RESOURCE LABEL	CURRENT CAPACITY	AVERAGE UTILIZATION	STANDARD DEVIATION	MAXIMUM UTILIZATION	CURRENT UTILIZATION
1	WC1	1	0.1685	0.3743	1	0
2	WC2	1	0.7136	0.4521	1	1

RESOURCE NUMBER	RESOURCE LABEL	CURRENT AVAILABLE	AVERAGE AVAILABLE	MINIMUM AVAILABLE	MAXIMUM AVAILABLE
1	WC1	1	0.8315	0	1
2	WC2	0	0.2864	0	1

GATE STATISTICS

GATE NUMBER	GATE LABEL	CURRENT STATUS	PCT. OF TIME OPEN
1	CR1	OPEN	0.9890
2	CR2	OPEN	0.9894

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

SIMULATION PROJECT TANKS   BY J. R. LEWIS

DATE 1/ 4/1984   RUN NUMBER 3 OF 10

CURRENT TIME 0.3600E+03
STATISTICAL ARRAYS CLEARED AT TIME 0.0000E+00

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
TANK TIME	0.8912E+00	0.1962E+00	0.2202E+00	0.6823E+00	0.4425E+01	664
TOTAL TIME	0.1032E+01	0.2611E+00	0.2530E+00	0.7111E+00	0.4548E+01	664

STATISTICS FOR TIME-PERSISTENT VARIABLES

	MEAN VALUE	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	TIME INTERVAL	CURRENT VALUE
NUMBER IN SYS. 1	0.3360E+03	0.1913E+03	0.0000E+00	0.6640E+03	0.3600E+03	0.6640E+03
NUMBER OF BRKDWN	0.9563E+01	0.6280E+01	0.0000E+00	0.2200E+02	0.3600E+03	0.2200E+02
NUMBER OF BRKDOW	0.2167E+01	0.1157E+01	0.0000E+00	0.4000E+01	0.3600E+03	0.4000E+01
TON OUTPUT	0.4641E+03	0.2639E+03	0.0000E+00	0.9193E+03	0.3600E+03	0.9193E+03

FILE STATISTICS

FILE NUMBER	ASSOCIATED NODE TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAITING TIME
1	AWAIT	0.0345	0.1824	1	0	0.0047
2	AWAIT	0.0000	0.0000	1	0	0.0000
3	AWAIT	0.0020	0.0445	1	0	0.0011
4	AWAIT	0.0027	0.0517	1	0	0.0002
5	CALENDAR	5.6135	1.1599	9	7	0.1240

RESOURCE STATISTICS

RESOURCE NUMBER	RESOURCE LABEL	CURRENT CAPACITY	AVERAGE UTILIZATION	STANDARD DEVIATION	MAXIMUM UTILIZATION	CURRENT UTILIZATION
1	WC1	1	0.1553	0.3622	1	0
2	WC2	1	0.6893	0.4628	1	1

RESOURCE NUMBER	RESOURCE LABEL	CURRENT AVAILABLE	AVERAGE AVAILABLE	MINIMUM AVAILABLE	MAXIMUM AVAILABLE
1	WC1	1	0.8447	0	1
2	WC2	0	0.3107	0	1

GATE STATISTICS

GATE NUMBER	GATE LABEL	CURRENT STATUS	PCT. OF TIME OPEN
1	CR1	OPEN	0.9595
2	CR2	OPEN	0.9958

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

SIMULATION PROJECT TANKS   BY J. R. LEWIS

DATE 1/ 4/1984   RUN NUMBER 4 OF 10

CURRENT TIME 0.3600E+03
STATISTICAL ARRAYS CLEARED AT TIME 0.0000E+00

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
TANK TIME	0.8747E+00	0.5970E-01	0.6826E-01	0.6349E+00	0.1285E+01	687
TOTAL TIME	0.1026E+01	0.1742E+00	0.1697E+00	0.6412E+00	0.1813E+01	686

STATISTICS FOR TIME-PERSISTENT VARIABLES

	MEAN VALUE	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	TIME INTERVAL	CURRENT VALUE
NUMBER IN SYS. 1	0.3431E+03	0.1984E+03	0.0000E+00	0.6860E+03	0.3600E+03	0.6860E+03
NUMBER OF BRKDWN	0.2134E+01	0.1157E+01	0.0000E+00	0.5000E+01	0.3600E+03	0.5000E+01
NUMBER OF BRKDOW	0.3167E+01	0.1985E+01	0.0000E+00	0.6000E+01	0.3600E+03	0.6000E+01
TON OUTPUT	0.4786E+03	0.2756E+03	0.0000E+00	0.9479E+03	0.3600E+03	0.9479E+03

FILE STATISTICS

FILE NUMBER	ASSOCIATED NODE TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAITING TIME
1	AWAIT	0.0018	0.0428	1	0	0.0002
2	AWAIT	0.0000	0.0000	1	0	0.0000
3	AWAIT	0.0021	0.0453	1	0	0.0011
4	AWAIT	0.0030	0.0544	1	0	0.0002
5	CALENDAR	5.0104	0.6299	8	7	0.1078

RESOURCE STATISTICS

RESOURCE NUMBER	RESOURCE LABEL	CURRENT CAPACITY	AVERAGE UTILIZATION	STANDARD DEVIATION	MAXIMUM UTILIZATION	CURRENT UTILIZATION
1	WC1	1	0.1605	0.3671	1	1
2	WC2	1	0.7152	0.4513	1	1

RESOURCE NUMBER	RESOURCE LABEL	CURRENT AVAILABLE	AVERAGE AVAILABLE	MINIMUM AVAILABLE	MAXIMUM AVAILABLE
1	WC1	0	0.8395	0	1
2	WC2	0	0.2848	0	1

GATE STATISTICS

GATE NUMBER	GATE LABEL	CURRENT STATUS	PCT. OF TIME OPEN
1	CR1	OPEN	0.9965
2	CR2	OPEN	0.9963

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

SIMULATION PROJECT TANKS   BY J. R. LEWIS

DATE 1/ 4/1984   RUN NUMBER 5 OF 10

CURRENT TIME 0.3600E+03
STATISTICAL ARRAYS CLEARED AT TIME 0.0000E+00

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
TANK TIME	0.8895E+00	0.1644E+00	0.1848E+00	0.6489E+00	0.3044E+01	674
TOTAL TIME	0.1044E+01	0.2319E+00	0.2221E+00	0.6864E+00	0.3094E+01	674

STATISTICS FOR TIME-PERSISTENT VARIABLES

	MEAN VALUE	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	TIME INTERVAL	CURRENT VALUE
NUMBER IN SYS. 1	0.3341E+03	0.1954E+03	0.0000E+00	0.6740E+03	0.3600E+03	0.6740E+03
NUMBER OF BRKDWN	0.4967E+01	0.2168E+01	0.0000E+00	0.8000E+01	0.3600E+03	0.8000E+01
NUMBER OF BRKDOW	0.2833E+01	0.1267E+01	0.0000E+00	0.4000E+01	0.3600E+03	0.4000E+01
TON OUTPUT	0.4404E+03	0.2590E+03	0.0000E+00	0.8982E+03	0.3600E+03	0.8982E+03

FILE STATISTICS

FILE NUMBER	ASSOCIATED NODE TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAITING TIME
1	AWAIT	0.0209	0.1431	1	0	0.0028
2	AWAIT	0.0009	0.0297	1	0	0.0005
3	AWAIT	0.0068	0.0822	1	0	0.0036
4	AWAIT	0.0056	0.0746	1	0	0.0004
5	CALENDAR	3.9960	0.6190	6	3	0.0879

RESOURCE STATISTICS

RESOURCE NUMBER	RESOURCE LABEL	CURRENT CAPACITY	AVERAGE UTILIZATION	STANDARD DEVIATION	MAXIMUM UTILIZATION	CURRENT UTILIZATION
1	WC1	1	0.1626	0.3690	1	1
2	WC2	1	0.7056	0.4558	1	0

RESOURCE NUMBER	RESOURCE LABEL	CURRENT AVAILABLE	AVERAGE AVAILABLE	MINIMUM AVAILABLE	MAXIMUM AVAILABLE
1	WC1	0	0.8374	0	1
2	WC2	1	0.2944	0	1

GATE STATISTICS

GATE NUMBER	GATE LABEL	CURRENT STATUS	PCT. OF TIME OPEN
1	CR1	OPEN	0.9772
2	CR2	OPEN	0.9934

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

SIMULATION PROJECT TANKS　　　BY J. R. LEWIS

DATE 1/ 4/1984　　　RUN NUMBER 6 OF 10

CURRENT TIME 0.3600E+03
STATISTICAL ARRAYS CLEARED AT TIME 0.0000E+00

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
TANK TIME	0.8955E+00	0.2201E+00	0.2458E+00	0.6513E+00	0.4002E+01	671
TOTAL TIME	0.1044E+01	0.2793E+00	0.2676E+00	0.6369E+00	0.4066E+01	670

STATISTICS FOR TIME-PERSISTENT VARIABLES

	MEAN VALUE	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	TIME INTERVAL	CURRENT VALUE
NUMBER IN SYS. 1	0.3346E+03	0.1925E+03	0.0000E+00	0.6700E+03	0.3600E+03	0.6700E+03
NUMBER OF BRKDWN	0.4669E+01	0.3006E+01	0.0000E+00	0.9000E+01	0.3600E+03	0.9000E+01
NUMBER OF BRKDOW	0.5667E+00	0.8439E+00	0.0000E+00	0.2000E+01	0.3600E+03	0.2000E+01
TON OUTPUT	0.4391E+03	0.2475E+03	0.0000E+00	0.8835E+03	0.3600E+03	0.8835E+03

FILE STATISTICS

FILE NUMBER	ASSOCIATED NODE TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAITING TIME
1	AWAIT	0.0215	0.1450	1	0	0.0029
2	AWAIT	0.0062	0.0787	1	0	0.0033
3	AWAIT	0.0109	0.1038	1	0	0.0058
4	AWAIT	0.0097	0.0983	1	0	0.0008
5	CALENDAR	4.6390	0.7524	7	6	0.1023

RESOURCE STATISTICS

RESOURCE NUMBER	RESOURCE LABEL	CURRENT CAPACITY	AVERAGE UTILIZATION	STANDARD DEVIATION	MAXIMUM UTILIZATION	CURRENT UTILIZATION
1	WC1	1	0.1654	0.3716	1	0
2	WC2	1	0.7048	0.4562	1	1

RESOURCE NUMBER	RESOURCE LABEL	CURRENT AVAILABLE	AVERAGE AVAILABLE	MINIMUM AVAILABLE	MAXIMUM AVAILABLE
1	WC1	1	0.8346	0	1
2	WC2	0	0.2952	0	1

GATE STATISTICS

GATE NUMBER	GATE LABEL	CURRENT STATUS	PCT. OF TIME OPEN
1	CR1	OPEN	0.9761
2	CR2	OPEN	0.9899

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

SIMULATION PROJECT TANKS BY J. R. LEWIS

DATE 1/ 4/1984 RUN NUMBER 7 OF 10

CURRENT TIME 0.3600E+03
STATISTICAL ARRAYS CLEARED AT TIME 0.0000E+00

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
TANK TIME	0.8734E+00	0.7591E-01	0.8690E-01	0.6677E+00	0.1725E+01	690
TOTAL TIME	0.1016E+01	0.1761E+00	0.1734E+00	0.7128E+00	0.2150E+01	689

STATISTICS FOR TIME-PERSISTENT VARIABLES

	MEAN VALUE	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	TIME INTERVAL	CURRENT VALUE
NUMBER IN SYS. 1	0.3442E+03	0.1998E+03	0.0000E+00	0.6890E+03	0.3600E+03	0.6890E+03
NUMBER OF BRKDWN	0.2667E+00	0.4422E+00	0.0000E+00	0.2000E+01	0.3600E+03	0.2000E+01
NUMBER OF BRKDOW	0.6667E+00	0.1075E+01	0.0000E+00	0.4000E+01	0.3600E+03	0.4000E+01
TON OUTPUT	0.4366E+03	0.2569E+03	0.0000E+00	0.9029E+03	0.3600E+03	0.9029E+03

FILE STATISTICS

FILE NUMBER	ASSOCIATED NODE TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAITING TIME
1	AWAIT	0.0000	0.0000	0	0	0.0000
2	AWAIT	0.0010	0.0312	1	0	0.0005
3	AWAIT	0.0059	0.0765	1	0	0.0031
4	AWAIT	0.0048	0.0689	1	0	0.0004
5	CALENDAR	4.0126	0.5589	7	4	0.0864

RESOURCE STATISTICS

RESOURCE NUMBER	RESOURCE LABEL	CURRENT CAPACITY	AVERAGE UTILIZATION	STANDARD DEVIATION	MAXIMUM UTILIZATION	CURRENT UTILIZATION
1	WC1	1	0.1643	0.3706	1	0
2	WC2	1	0.7163	0.4508	1	0

RESOURCE NUMBER	RESOURCE LABEL	CURRENT AVAILABLE	AVERAGE AVAILABLE	MINIMUM AVAILABLE	MAXIMUM AVAILABLE
1	WC1	1	0.8357	0	1
2	WC2	1	0.2837	0	1

GATE STATISTICS

GATE NUMBER	GATE LABEL	CURRENT STATUS	PCT. OF TIME OPEN
1	CR1	OPEN	0.9995
2	CR2	OPEN	0.9937

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

SIMULATION PROJECT TANKS   BY J. R. LEWIS

DATE 1/ 4/1984   RUN NUMBER 8 OF 10

CURRENT TIME 0.3600E+03
STATISTICAL ARRAYS CLEARED AT TIME 0.0000E+00

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
TANK TIME	0.9027E+00	0.2554E+00	0.2829E+00	0.6697E+00	0.3728E+01	672
TOTAL TIME	0.1058E+01	0.3159E+00	0.2987E+00	0.7036E+00	0.4079E+01	672

STATISTICS FOR TIME-PERSISTENT VARIABLES

	MEAN VALUE	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	TIME INTERVAL	CURRENT VALUE
NUMBER IN SYS. 1	0.3382E+03	0.1956E+03	0.0000E+00	0.6720E+03	0.3600E+03	0.6720E+03
NUMBER OF BRKDWN	0.3928E+01	0.2165E+01	0.0000E+00	0.9000E+01	0.3600E+03	0.9000E+01
NUMBER OF BRKDOW	0.4131E+01	0.2391E+01	0.0000E+00	0.7000E+01	0.3600E+03	0.7000E+01
TON OUTPUT	0.4844E+03	0.2770E+03	0.0000E+00	0.9518E+03	0.3600E+03	0.9518E+03

FILE STATISTICS

FILE NUMBER	ASSOCIATED NODE TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAITING TIME
1	AWAIT	0.0179	0.1325	1	0	0.0024
2	AWAIT	0.0094	0.0966	1	0	0.0050
3	AWAIT	0.0181	0.1335	1	0	0.0097
4	AWAIT	0.0160	0.1254	1	0	0.0012
5	CALENDAR	4.9887	0.7668	8	7	0.1095

RESOURCE STATISTICS

RESOURCE NUMBER	RESOURCE LABEL	CURRENT CAPACITY	AVERAGE UTILIZATION	STANDARD DEVIATION	MAXIMUM UTILIZATION	CURRENT UTILIZATION
1	WC1	1	0.1728	0.3781	1	0
2	WC2	1	0.7152	0.4513	1	1

RESOURCE NUMBER	RESOURCE LABEL	CURRENT AVAILABLE	AVERAGE AVAILABLE	MINIMUM AVAILABLE	MAXIMUM AVAILABLE
1	WC1	1	0.8272	0	1
2	WC2	0	0.2848	0	1

GATE STATISTICS

GATE NUMBER	GATE LABEL	CURRENT STATUS	PCT. OF TIME OPEN
1	CR1	OPEN	0.9796
2	CR2	OPEN	0.9827

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

SIMULATION PROJECT TANKS   BY J. R. LEWIS

DATE 1/ 4/1984   RUN NUMBER 9 OF 10

CURRENT TIME 0.3600E+03
STATISTICAL ARRAYS CLEARED AT TIME 0.0000E+00

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
TANK TIME	0.8829E+00	0.1064E+00	0.1205E+00	0.6187E+00	0.1994E+01	684
TOTAL TIME	0.1039E+01	0.1945E+00	0.1871E+00	0.7133E+00	0.2154E+01	684

STATISTICS FOR TIME-PERSISTENT VARIABLES

	MEAN VALUE	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	TIME INTERVAL	CURRENT VALUE
NUMBER IN SYS. 1	0.3404E+03	0.1986E+03	0.0000E+00	0.6840E+03	0.3600E+03	0.6840E+03
NUMBER OF BRKDWN	0.1767E+01	0.6155E+00	0.0000E+00	0.3000E+01	0.3600E+03	0.3000E+01
NUMBER OF BRKDOW	0.1733E+01	0.1413E+01	0.0000E+00	0.4000E+01	0.3600E+03	0.4000E+01
TON OUTPUT	0.4509E+03	0.2690E+03	0.0000E+00	0.9239E+03	0.3600E+03	0.9239E+03

FILE STATISTICS

FILE NUMBER	ASSOCIATED NODE TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAITING TIME
1	AWAIT	0.0036	0.0597	1	0	0.0005
2	AWAIT	0.0032	0.0564	1	0	0.0017
3	AWAIT	0.0079	0.0884	1	0	0.0041
4	AWAIT	0.0068	0.0823	1	0	0.0005
5	CALENDAR	4.0289	0.5689	6	3	0.0875

RESOURCE STATISTICS

RESOURCE NUMBER	RESOURCE LABEL	CURRENT CAPACITY	AVERAGE UTILIZATION	STANDARD DEVIATION	MAXIMUM UTILIZATION	CURRENT UTILIZATION
1	WC1	1	0.1653	0.3714	1	0
2	WC2	1	0.7172	0.4504	1	0

RESOURCE NUMBER	RESOURCE LABEL	CURRENT AVAILABLE	AVERAGE AVAILABLE	MINIMUM AVAILABLE	MAXIMUM AVAILABLE
1	WC1	1	0.8347	0	1
2	WC2	1	0.2828	0	1

GATE STATISTICS

GATE NUMBER	GATE LABEL	CURRENT STATUS	PCT. OF TIME OPEN
1	CR1	OPEN	0.9952
2	CR2	OPEN	0.9926

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

SIMULATION PROJECT TANKS　　　　BY J. R. LEWIS

DATE 1/ 4/1984　　　　RUN NUMBER 10 OF 10

CURRENT TIME 0.3600E+03
STATISTICAL ARRAYS CLEARED AT TIME 0.0000E+00

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBSERVATIONS
TANK TIME	0.8785E+00	0.1250E+00	0.1423E+00	0.6739E+00	0.3411E+01	685
TOTAL TIME	0.1025E+01	0.1945E+00	0.1898E+00	0.6992E+00	0.3492E+01	685

STATISTICS FOR TIME-PERSISTENT VARIABLES

	MEAN VALUE	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	TIME INTERVAL	CURRENT VALUE
NUMBER IN SYS. 1	0.3390E+03	0.1983E+03	0.0000E+00	0.6850E+03	0.3600E+03	0.6850E+03
NUMBER OF BRKDWN	0.1300E+01	0.8622E+00	0.0000E+00	0.2000E+01	0.3600E+03	0.2000E+01
NUMBER OF BRKDOW	0.2333E+01	0.1274E+01	0.0000E+00	0.5000E+01	0.3600E+03	0.5000E+01
TON OUTPUT	0.4842E+03	0.2720E+03	0.0000E+00	0.9511E+03	0.3600E+03	0.9511E+03

FILE STATISTICS

FILE NUMBER	ASSOCIATED NODE TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVERAGE WAITING TIME
1	AWAIT	0.0075	0.0865	1	0	0.0010
2	AWAIT	0.0007	0.0264	1	0	0.0004
3	AWAIT	0.0062	0.0787	1	0	0.0033
4	AWAIT	0.0047	0.0683	1	0	0.0004
5	CALENDAR	4.0085	0.5704	6	4	0.0869

RESOURCE STATISTICS

RESOURCE NUMBER	RESOURCE LABEL	CURRENT CAPACITY	AVERAGE UTILIZATION	STANDARD DEVIATION	MAXIMUM UTILIZATION	CURRENT UTILIZATION
1	WC1	1	0.1644	0.3707	1	0
2	WC2	1	0.7144	0.4517	1	1

RESOURCE NUMBER	RESOURCE LABEL	CURRENT AVAILABLE	AVERAGE AVAILABLE	MINIMUM AVAILABLE	MAXIMUM AVAILABLE
1	WC1	1	0.8356	0	1
2	WC2	0	0.2856	0	1

GATE STATISTICS

GATE NUMBER	GATE LABEL	CURRENT STATUS	PCT. OF TIME OPEN
1	CR1	OPEN	0.9921
2	CR2	OPEN	0.9942

APPENDIX H

CAN-Q OUTPUT

ROUTING FOR PRODUCT TYPE: LUBE

OPERATION NUMBER	STATION NUMBER	PROCESSING TIME	OPERATION FREQUENCY
1	1	6.710	1.000
2	2	6.680	1.000
3	3	.710	1.000
4	4	13.600	1.000
5	3	.710	1.000
6	5	.720	1.000
7	6	6.740	1.000
8	7	.710	1.000
9	8	.950	1.000
10	9	6.670	1.000
11	10	2.300	1.000

WORKLOAD SUMMARY FOR THIS PRODUCT TYPE

STATION		NUMBER OF VISITS	VISIT FREQUENCY	TOTAL PROCESS TIME	AVERAGE PROCESS TIME	RELATIVE WORKLOAD
1	HOLD	1.000	.091	6.710	6.710	.610
2	CAUS	1.000	.091	6.680	6.680	.607
3	CW I	2.000	.182	1.420	.710	.129
4	ACID	1.000	.091	13.600	13.600	1.236
5	HW	1.000	.091	.720	.720	.065
6	PHOS	1.000	.091	6.740	6.740	.613
7	CW II	1.000	.091	.710	.710	.065
8	NEUT	1.000	.091	.950	.950	.086
9	SOAP	1.000	.091	6.670	6.670	.606
10	DRY	1.000	.091	2.300	2.300	.209

AVERAGE NUMBER OF OPERATIONS TO COMPLETE ONE 11.000
DESIRED FRACTION OF PRODUCTION = .890

VALUE OF ONE ITEM = 1.00

ROUTING FOR PRODUCT TYPE: PHO

OPERATION NUMBER	STATION NUMBER	PROCESSING TIME	OPERATION FREQUENCY
1	1	6.710	1.000
2	2	6.680	1.000
3	3	.710	1.000
4	4	13.600	1.000
5	3	.710	1.000
6	5	.720	1.000
7	6	6.740	1.000
8	7	.710	1.000
9	10	2.300	1.000

WORKLOAD SUMMARY FOR THIS PRODUCT TYPE

STATION		NUMBER OF VISITS	VISIT FREQUENCY	TOTAL PROCESS TIME	AVERAGE PROCESS TIME	RELATIVE WORKLOAD
1	HOLD	1.000	.111	6.710	6.710	.746
2	CAUS	1.000	.111	6.680	6.680	.742
3	CW I	2.000	.222	1.420	.710	.158
4	ACID	1.000	.111	13.600	13.600	1.511
5	HW	1.000	.111	.720	.720	.080
6	PHOS	1.000	.111	6.740	6.740	.749
7	CW II	1.000	.111	.710	.710	.079
10	DRY	1.000	.111	2.300	2.300	.256

AVERAGE NUMBER OF OPERATIONS TO COMPLETE ONE 9.000
DESIRED FRACTION OF PRODUCTION = .040

VALUE OF ONE ITEM = 1.00

ROUTING FOR PRODUCT TYPE: TRI

OPERATION NUMBER	STATION NUMBER	PROCESSING TIME	OPERATION FREQUENCY
1	1	6.710	1.000
2	2	6.680	1.000
3	3	.710	1.000
4	4	13.600	1.000
5	3	.710	1.000
6	5	.720	1.000
7	10	2.300	1.000

WORKLOAD SUMMARY FOR THIS PRODUCT TYPE

STATION		NUMBER OF VISITS	VISIT FREQUENCY	TOTAL PROCESS TIME	AVERAGE PROCESS TIME	RELATIVE WORKLOAD
1	HOLD	1.000	.143	6.710	6.710	.959
2	CAUS	1.000	.143	6.680	6.680	.954
3	CW I	2.000	.286	1.420	.710	.203
4	ACID	1.000	.143	13.600	13.600	1.943
5	HW	1.000	.143	.720	.720	.103
10	DRY	1.000	.143	2.300	2.300	.329

AVERAGE NUMBER OF OPERATIONS TO COMPLETE ONE 7.000
DESIRED FRACTION OF PRODUCTION = .070

VALUE OF ONE ITEM = 1.00

INPUT DATA SUMMARY

	STATION	NUMBER OF SERVERS	VISIT FREQUENCY	AVERAGE PROCESSING TIME	RELATIVE WORKLOAD	WORKLOAD PER SERVER
1	HOLD	1	.09398	6.71000	.63064	.6306
2	CAUS	1	.09398	6.68000	.62782	.6278
3	CW I	1	.18797	.71000	.13346	.1335
4	ACID	1	.09398	13.60000	1.27820	1.2782
5	HW	1	.09398	.72000	.06767	.0677
6	PHOS	1	.08741	6.74000	.58912	.5891
7	CW II	1	.08741	.71000	.06206	.0621
8	NEUT	1	.08365	.95000	.07946	.0795
9	SOAP	1	.08365	6.67000	.55792	.5579
10	DRY	1	.09398	2.30000	.21617	.2162
11	CRANE	1	.09398	.18000	.18000	.1800

NUMBER OF ITEMS IN SYSTEM = 2

MEAN NUMBER OF OPERATIONS TO COMPLETE AN ITEM 10.64000

SYSTEM PERFORMANCE MEASURES

PRODUCTION RATE = 2.192 ITEMS PER HOUR

PRODUCTION RATES BY PRODUCT TYPE

	NUMBER	VALUE
LUBE	1.951	1.951
PHO	.088	.088
TRI	.153	.153

TOTAL VALUE = 2.192

AVERAGE TIME IN SYSTEM = 54.74 MINUTES

PROCESSING	45.14
TRAVELING	1.92
WAITING	7.69

FUNCTIONS OF N, NUMBER OF ITEMS IN THE SYSTEM

N	PRODUCTION RATE	AVERAGE TIME IN THE SYSTEM
1	1.275	47.056
2	2.192	54.744
3	2.854	63.063
4	3.332	72.029
5	3.674	81.649
6	3.917	91.917
7	4.085	102.804
.	.	.
.	.	.
.	.	.
INF	4.412	INF

THE BOTTLENECK STATION IS 4

SUMMARY FOR STATION NUMBER 1 : HOLD

NUMBER OF SERVERS	SERVER UTILIZATION	AVE. NO. OF BUSY SERVERS
1	.245	.245

STEADY STATE AVERAGE NUMBER OF :

ITEMS WAITING	.560
ITEMS IN PROCESS	.245
ITEMS WAITING	.315

AVERAGE TIME SPENT AT THIS STATION	PER OPERATION	PER ITEM
TOTAL TIME (MINUTES)	15.334	15.334
PROCESSING	6.710	6.710
WAITING	8.624	8.624

FRACTION OF TIME	X ITEMS AT STATION	X ITEMS EXCEEDED
X = 0	.7549	.2451
X = 1	.2451	.0000
X = 2	.0350	#####

SUMMARY FOR STATION NUMBER 2 : CAUS

NUMBER OF SERVERS	SERVER UTILIZATION	AVE. NO. OF BUSY SERVERS
1	.244	.244

STEADY STATE AVERAGE NUMBER OF :

ITEMS WAITING	.557
ITEMS IN PROCESS	.244
ITEMS WAITING	.313

AVERAGE TIME SPENT AT THIS STATION	PER OPERATION	PER ITEM
TOTAL TIME (MINUTES)	15.257	15.257
PROCESSING	6.680	6.680
WAITING	8.577	8.577

FRACTION OF TIME	X ITEMS AT STATION	X ITEMS EXCEEDED
X = 0	.7560	.2440
X = 1	.2440	.0000
X = 2	.0346	#####

SUMMARY FOR STATION NUMBER 3 : CW I

NUMBER OF SERVERS	SERVER UTILIZATION	AVE. NO. OF BUSY SERVERS
1	.052	.052

STEADY STATE AVERAGE NUMBER OF :

ITEMS WAITING	.107
ITEMS IN PROCESS	.052
ITEMS WAITING	.055

AVERAGE TIME SPENT AT THIS STATION	PER OPERATION	PER ITEM
TOTAL TIME (MINUTES)	1.463	2.926
PROCESSING	.710	1.420
WAITING	.753	1.506

FRACTION OF TIME	X ITEMS AT STATION	X ITEMS EXCEEDED
X = 0	.9481	.0519
X = 1	.0519	.0000
X = 2	.0016	#####

SUMMARY FOR STATION NUMBER 4 : ACID

NUMBER OF SERVERS	SERVER UTILIZATION	AVE. NO. OF BUSY SERVERS
1	.497	.497

STEADY STATE AVERAGE NUMBER OF :

ITEMS WAITING	1.281
ITEMS IN PROCESS	.497
ITEMS WAITING	.784

AVERAGE TIME SPENT AT THIS STATION	PER OPERATION	PER ITEM
TOTAL TIME (MINUTES)	35.061	35.061
PROCESSING	13.600	13.600
WAITING	21.461	21.461

FRACTION OF TIME	X ITEMS AT STATION	X ITEMS EXCEEDED
X = 0	.5031	.4969
X = 1	.4969	.0000
X = 2	.1436	#####

SUMMARY FOR STATION NUMBER 5 : HW

NUMBER OF SERVERS	SERVER UTILIZATION	AVE. NO. OF BUSY SERVERS
1	.026	.026

STEADY STATE AVERAGE NUMBER OF :

ITEMS WAITING	.053
ITEMS IN PROCESS	.026
ITEMS WAITING	.027

AVERAGE TIME SPENT AT THIS STATION	PER OPERATION	PER ITEM
TOTAL TIME (MINUTES)	1.462	1.462
PROCESSING	.720	.720
WAITING	.742	.742

FRACTION OF TIME	X ITEMS AT STATION	X ITEMS EXCEEDED
X = 0	.9737	.0263
X = 1	.0263	.0000
X = 2	.0004	#####

SUMMARY FOR STATION NUMBER 6 : PHOS

NUMBER OF SERVERS	SERVER UTILIZATION	AVE. NO. OF BUSY SERVERS
1	.229	.229

STEADY STATE AVERAGE NUMBER OF :

ITEMS WAITING	.519
ITEMS IN PROCESS	.229
ITEMS WAITING	.290

AVERAGE TIME SPENT AT THIS STATION	PER OPERATION	PER ITEM
TOTAL TIME (MINUTES)	15.276	14.206
PROCESSING	6.740	6.268
WAITING	8.536	7.938

FRACTION OF TIME	X ITEMS AT STATION	X ITEMS EXCEEDED
X = 0	.7710	.2290
X = 1	.2290	.0000
X = 2	.0305	#####

SUMMARY FOR STATION NUMBER 7 : CW II

NUMBER OF SERVERS	SERVER UTILIZATION	AVE. NO. OF BUSY SERVERS
1	.024	.024

STEADY STATE AVERAGE NUMBER OF :

ITEMS WAITING	.049
ITEMS IN PROCESS	.024
ITEMS WAITING	.025

AVERAGE TIME SPENT AT THIS STATION	PER OPERATION	PER ITEM
TOTAL TIME (MINUTES)	1.440	1.339
PROCESSING	.710	.660
WAITING	.730	.679

FRACTION OF TIME	X ITEMS AT STATION	X ITEMS EXCEEDED
X = 0	.9759	.0241
X = 1	.0241	.0000
X = 2	.0003	#####

SUMMARY FOR STATION NUMBER 9 : SOAP

NUMBER OF SERVERS	SERVER UTILIZATION	AVE. NO. OF BUSY SERVERS
1	.217	.217

STEADY STATE AVERAGE NUMBER OF :

ITEMS WAITING	.488
ITEMS IN PROCESS	.217
ITEMS WAITING	.272

AVERAGE TIME SPENT AT THIS STATION	PER OPERATION	PER ITEM
TOTAL TIME (MINUTES)	15.023	13.370
PROCESSING	6.670	5.936
WAITING	8.353	7.434

FRACTION OF TIME	X ITEMS AT STATION	X ITEMS EXCEEDED
X = 0	.7831	.2169
X = 1	.2169	.0000
X = 2	.0274	#####

SUMMARY FOR STATION NUMBER 8 : NEUT

NUMBER OF SERVERS	SERVER UTILIZATION	AVE. NO. OF BUSY SERVERS
1	.031	.031

STEADY STATE AVERAGE NUMBER OF :

ITEMS WAITING	.063
ITEMS IN PROCESS	.031
ITEMS WAITING	.032

AVERAGE TIME SPENT AT THIS STATION	PER OPERATION	PER ITEM
TOTAL TIME (MINUTES)	1.934	1.721
PROCESSING	.950	.846
WAITING	.984	.876

FRACTION OF TIME	X ITEMS AT STATION	X ITEMS EXCEEDED
X = 0	.9691	.0309
X = 1	.0309	.0000
X = 2	.0006	#####

SUMMARY FOR STATION NUMBER 10 : DRY

NUMBER OF SERVERS	SERVER UTILIZATION	AVE. NO. OF BUSY SERVERS
1	.084	.084

STEADY STATE AVERAGE NUMBER OF :

ITEMS WAITING	.176
ITEMS IN PROCESS	.084
ITEMS WAITING	.092

AVERAGE TIME SPENT AT THIS STATION	PER OPERATION	PER ITEM
TOTAL TIME (MINUTES)	4.825	4.825
PROCESSING	2.300	2.300
WAITING	2.525	2.525

FRACTION OF TIME	X ITEMS AT STATION	X ITEMS EXCEEDED
X = 0	.9160	.0840
X = 1	.0840	.0000
X = 2	.0041	#####

SUMMARY FOR STATION NUMBER 11 : CRANE

NUMBER OF SERVERS	SERVER UTILIZATION	AVE. NO. OF BUSY SERVERS
1	.070	.070

STEADY STATE AVERAGE NUMBER OF :

ITEMS WAITING	.146
ITEMS IN PROCESS	.070
ITEMS WAITING	.076

AVERAGE TIME SPENT AT THIS STATION	PER OPERATION	PER ITEM
TOTAL TIME (MINUTES)	.375	3.986
PROCESSING	.180	1.915
WAITING	.195	2.071

FRACTION OF TIME	X ITEMS AT STATION	X ITEMS EXCEEDED
X = 0	.9300	.0700
X = 1	.0700	.0000
X = 2	.0028	#####

SENSITIVITY INFORMATION

A ONE MINUTE DECREASE IN PROCESSING TIME AT STATION	WILL INCREASE THE PRODUCTION RATE
1 HOLD	.136 UNITS/HOUR (6.2235 PERCENT)
2 CAUS	.136 UNITS/HOUR (6.2189 PERCENT)
3 CW I	.237 UNITS/HOUR (10.8042 PERCENT)
4 ACID	.160 UNITS/HOUR (7.2934 PERCENT)
5 HW	.116 UNITS/HOUR (5.2934 PERCENT)
6 PHOS	.125 UNITS/HOUR (5.7241 PERCENT)
7 CW II	.108 UNITS/HOUR (4.9142 PERCENT)
8 NEUT	.104 UNITS/HOUR (4.7285 PERCENT)
9 SOAP	.119 UNITS/HOUR (5.4320 PERCENT)
10 DRY	.121 UNITS/HOUR (5.5387 PERCENT)
11 CRANE	1.278 UNITS/HOUR (58.2965 PERCENT)

A ONE PERCENT DECREASE IN PROCESSING TIME AT STATION	WILL INCREASE THE PRODUCTION RATE
1 HOLD	.009 UNITS/HOUR (.4176 PERCENT)
2 CAUS	.009 UNITS/HOUR (.4154 PERCENT)
3 CW I	.002 UNITS/HOUR (.0767 PERCENT)
4 ACID	.022 UNITS/HOUR (.9919 PERCENT)
5 HW	.001 UNITS/HOUR (.0381 PERCENT)
6 PHOS	.008 UNITS/HOUR (.3858 PERCENT)
7 CW II	.001 UNITS/HOUR (.0349 PERCENT)
8 NEUT	.001 UNITS/HOUR (.0449 PERCENT)
9 SOAP	.008 UNITS/HOUR (.3623 PERCENT)
10 DRY	.003 UNITS/HOUR (.1274 PERCENT)
11 CRANE	.002 UNITS/HOUR (.1049 PERCENT)

A ONE MINUTE DECREASE IN RELATIVE UTILIZATION AT STATION	WILL INCREASE THE PRODUCTION RATE BY
1 HOLD	1.452 UNITS/HOUR (66.2184 PERCENT)
2 CAUS	1.450 UNITS/HOUR (66.1688 PERCENT)
3 CW I	1.260 UNITS/HOUR (57.4784 PERCENT)
4 ACID	1.701 UNITS/HOUR (77.6018 PERCENT)
5 HW	1.235 UNITS/HOUR (56.3218 PERCENT)
6 PHOS	1.436 UNITS/HOUR (65.4884 PERCENT)
7 CW II	1.232 UNITS/HOUR (56.2232 PERCENT)
8 NEUT	1.239 UNITS/HOUR (56.5292 PERCENT)
9 SOAP	1.424 UNITS/HOUR (64.9401 PERCENT)
10 DRY	1.292 UNITS/HOUR (58.9323 PERCENT)
11 CRANE	1.278 UNITS/HOUR (58.2965 PERCENT)

A DECREASE OF .01 IN THE PROPORTION OF PRODUCT TYPE	WILL INCREASE THE PRODUCTION RATE BY
LUBE	.065 ITEMS/HOUR (2.9771 PERCENT)
PHO	.055 ITEMS/HOUR (2.5195 PERCENT)
TRI	.045 ITEMS/HOUR (2.0671 PERCENT)

A DECREASE OF .01 IN THE PROPORTION OF PRODUCT TYPE	WILL INCREASE THE VALUE OF PRODUCTION PLAN BY
LUBE	.043 ITEMS/HOUR (1.9771 PERCENT)
PHO	.033 ITEMS/HOUR (1.5195 PERCENT)
TRI	.023 ITEMS/HOUR (1.0671 PERCENT)

VITA 2

John Russell Lewis

Candidate for the Degree of

Master of Science

Thesis: THE USE OF SIMULATION AND CAN-Q TO ANALYZE THE CLEANING AND LUBRICATING PROCESSES OF COLD DRAWN TUBING

Major Field: Industrial Engineering

Biographical:

Personal Data: Born in Sioux City, Iowa, August 11, 1959, the son of Thomas M. and Carolyn C. Lewis.

Education: Graduated from West DePere High School, DePere, Wisconsin, in May, 1977; received Bachelor of Science Degree in Industrial Engineering from Oklahoma State University in December, 1983; completed requirements for the Master of Science Degree at Oklahoma State University in May 1985.

Professional Experience: Teaching assistant, Department of Industrial Engineering, Oklahoma State University, January 1984 to May, 1984; consulting industrial engineer, Southwest Tube Manufacturing, Sand Springs, Oklahoma, June, 1981 to May, 1984.