EQUIPMENT CONFIGURATION STUDY
USING DIGITAL SIMULATION

by

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CHAPTER 1

INTRODUCTION

The amount of literature which has appeared concerning operations research techniques and their applications to manufacturing processes is voluminous. Simulation is no exception. Simulation (the word is used here synonymously with Digital Simulation) has been widely used as a convenient and effective approach in analyzing the problems encountered in job and flow shops and in evaluating queue disciplines of all kinds. As a management tool, simulation has been used to study situations ranging from congestion problems in the melting shop of a steel works (1), to the prediction of the manufacturing characteristics of custom integrated circuits (15). Almost every kind of manufacturing system has been simulated, throwing light on the features and modelling aspects which characterize the process.

The manufacture of any product can come under one of two classifications--manufacture on a batch-wise basis, manufacture on a continuous basis. A typical example of a batch production system is the melting shop in a steel mill, each batch being the contents of one furnace. The normal cycle of melting shop operations consists of charging the furnaces, melting the charge, refining the charge, casting into molds and fettling. Simulation was chosen as the technique to study the entire operation of such a melting shop (14). A flexible and fairly realistic model was constructed and helped make decisions regarding the operating policies under different conditions and locate the causes for production delays and analyze the adequacy/inadequacy of the equipment.

Youle (15) employed digital simulation and a Ferranti Mercury Computer to study the behavior of a multistage batchwise chemical plant with seventeen processing units in four stages, connected by a network of pipelines and manifolds. The simulation provided information on the plant performance under different operating conditions and the effects of additional processing units and reduction in the variability in cycle times in the reactors. The study was instrumental in locating the bottlenecks in the process and helped plan expansion schemes.

Banbury and Taylor (1), in a study of congestion in the melting shop of a steelworks, investigated the effect of this congestion on the planned future production. The technique employed was simulation and the future production being envisaged involved a 25 percent increase in output. The shop operations were simulated under different priority conditions with regard to the material movement and handling. These, in turn, decided the working rules and the initial simulation runs provided data on what the output would be under these conditions. Subsequent runs indicated what the effects of the congestion should be, in order to attain a 25 percent increase in output. They also showed the need for an increase in the capacities of the equipment employed.

The present work is concerned with a chemical plant manufacturing one product using two raw materials. There are reactors at four stages and intermediate holding tanks prior to the first and fourth stage reactors. The object of the study is to simulate the system using logical configurations of the available equipment and analyze the characteristic features of the simulation and the model(s) derived therefrom.

The use of simulation as a management tool is relatively new. In this aspect, it consists of representing the real world in terms of a mathematical model that will react similarly to the situation after which it is patterned (2). By using digital computers, management can simulate the behavior of an entire business and manufacturing system in order to evaluate overall performance under the influence of interacting factors. Since computer simulation "compresses" the time of occurrences of future events into short intervals of present time, many variations of business situations and system behavior can be conveniently studied.

1.2. Plant to be simulated

1.2.1. Description of plant

This study has as its source the correspondence between Eastman Kodak Company and the Department of Industrial Engineering, Kansas State University.

The existing manufacturing system is shown in Figure 1.1. This equipment configuration can be considered to be the original arrangement, prior to the introduction of any changes at any stage of the process.

There are two raw materials, which are stored in tanks X and Y, which, it has been assumed, do not react chemically under normal conditions. A pump sends a mixture of these two materials to the two holding tanks 1 and 2, which are respectively the first units in the two parallel channels.

The materials are then sent to the reactors at stage 1 for the first of the four reactions. The material, which enters the reactor with a weight of 7 units, spends 5 hours in it before proceeding to the next processing unit, the reactor at stage 2. The material occupies this processor for 3 hours before proceeding to the third stage, where the reaction time is one hour.

After entering an intermediate storage, the fourth and final reaction of 1.75 hours takes place and the material that emerges from the fourth stage reactors is the finished product.

These times mentioned here are the mean reaction times. They have a certain variability associated with them and are uniformly distributed in their respective ranges. This is described later in this chapter.

The primary object of this study is a complete simulation of the entire process according to the existing configuration of equipment as shown in Figure 1.1. By adopting this approach, it was hoped that some light would be shed on the following aspects:

1. detecting the bottlenecks in the production line and ways to eliminate them,

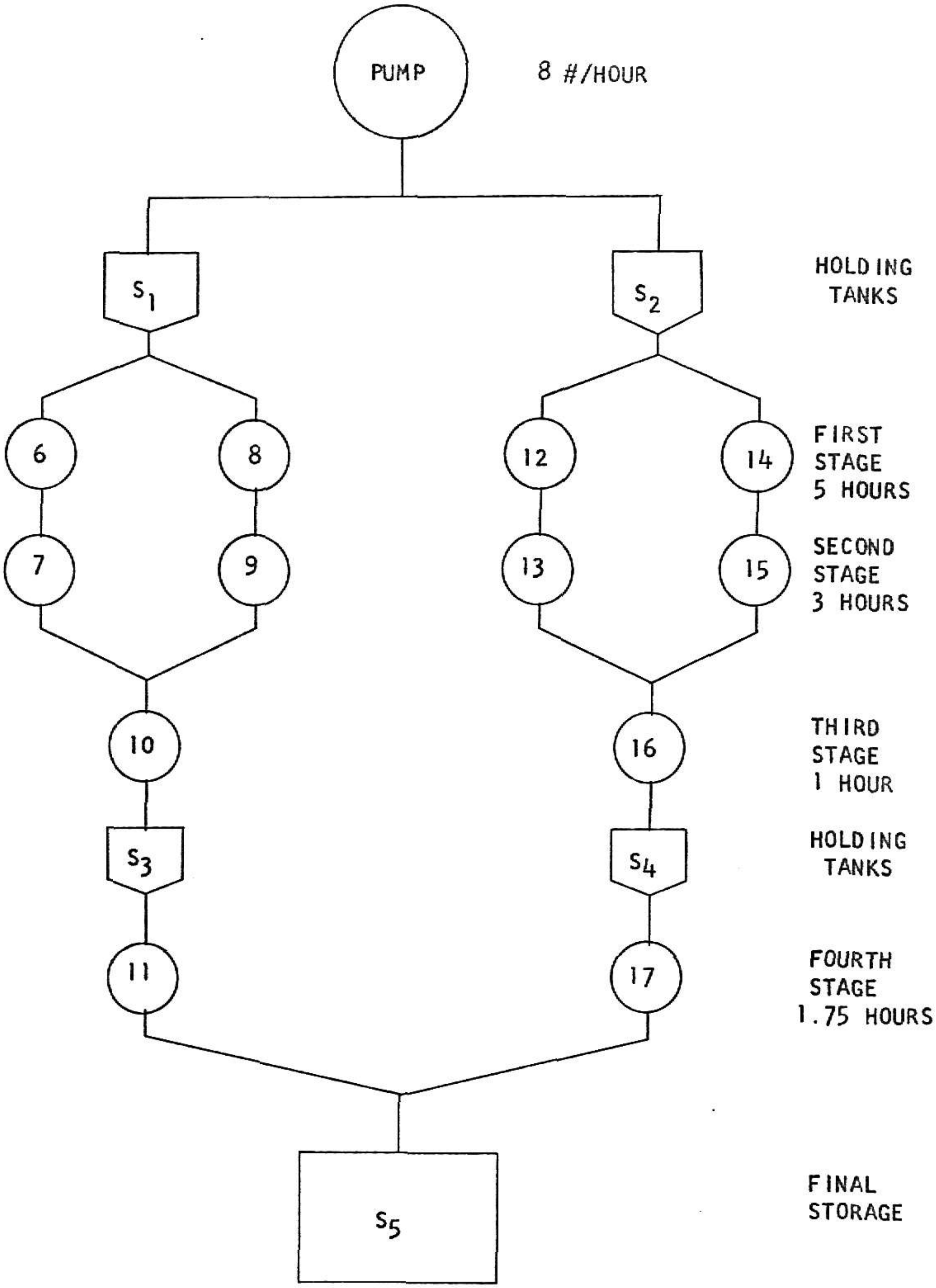


Figure 1.1. Equipment Configuration 1 (Models 1 and 2).

2. achieving greater efficiency in running the plant,

3. increasing the output from the process,

4. aid in planning expansion schemes.

From the simulation data obtained, appropriate changes were made in the arrangement of the processing units, the flow paths available to the material, pumping rates, incorporation of new manifolds and the priorities given to the facilities at the same stage, in an effort to realize the above-mentioned objectives.

The first configuration studied consists of four lines feeding from a single source and feeding into a single final storage. This is shown in Figure 1.1.

There are twelve reactors at four stages in this configuration and are numbered from 6 to 17. Each of them has been assumed to have a capacity of 7 pounds. There are four at the first stage, two on each symmetrical half of the configuration; four at the second stage, one immediately after each of the first stage reactors; two at the third stage; and two at the fourth stage, one for each reactor at the third stage.

The resident times in the four reaction stages have mean values of 5, 3, 1 and 1.75 hours respectively. There is a variability associated with these times. The respective ranges are 40, 30, 10 and 20 minutes, distributed uniformly about the mean times. The GPSS/360 program selects the processing times (in simulation clock units) within these ranges by giving equal probability to each number in that range.

There are intermediate holding tanks at two points in this arrangement, one in each of the two main channels immediately prior to the first and fourth stage reactors. The holding tanks have been assumed to have a capacity of 14 pounds each. The finished product from the two production lines flows into a final storage tank, which has an infinite capacity. This assumption of infinite capacity has been made in an attempt to simplify the model and to compensate for the lack of appropriate data regarding the distribution of the demand for the product.

In order to build the model and set up a computer program for it, the following approach has been employed.

STEP 1. Obtain the line diagram of the plant. Figure 1.1 is the line diagram for Configuration 1. The description of this arrangement has been given in brief.

STEP 2. Analyze the plant behavior.
The first configuration of the equipment is studied with regard to the location and arrangement of the processing units, storages and any special fixtures, which are either part of the existing set-up or part of any proposed alterations. This would include any valves (dual or multi-function), bypasses and manifolds.

Each reaction vessel is considered to be a Processing Unit of the system. The activities in any one unit are characterized by the processing time and this time has been referred to as the Cycle Time associated with that unit.

An assumption has been made in this study to the effect that the supply of the two raw materials is adequate for all time and that these two materials do not react except under specified conditions in the reactor vessels at the four stages. Such being the case, there are five activities associated with each processing unit. These are:

1. Charging the processing unit
2. Processing the material in the processing unit
3. Discharging the processed material
4. Waiting full
5. Waiting empty.

Under ideal working conditions, there should be no waiting, either full or empty. If such were the case, there would only be three activities--charging, processing and discharging. However, due to the inadequacy of connecting pipelines or due to the subsequent processing units being occupied, a certain amount of waiting is unavoidable. This may be either of two cases--waiting to receive fresh material, or waiting to discharge processed material.

STEP 3. A comprehensive program will be able to provide the analyst with the progress of every processing unit through all these five activities. In order to achieve this, certain questions need to be answered regarding the stage-to-stage transfer of material.

Regarding this transfer of material, it has been assumed that a processing unit, whenever it is in the appropriate state, "dumps" its contents into the subsequent processing unit. It has also been assumed that this latter unit is capable of receiving the contents of the previous stage on a bulk transfer basis, within the limitations imposed on it by its capacity.

As far as Configuration 1 is concerned, the processed material from the unit in stage 1 can flow into only one unit in the next stage. For instance, material from Unit 6 flows into Unit 7, and none other. However, a simple manifold between the two subchannels consisting of units 6 and 7 and 8 and 9 after Stage 1, would permit the flow of material from Unit 6 (and Unit 8) into either of the two Units 7 and 9.

Some priority rules which are applicable to this configuration may be stated as follows:

1) A unit cannot discharge material into another, which is partially full or partially empty.
2) When two units are in a position to receive a fresh charge, the unit on the left is given priority over that on the right. (This rule has been modified at a later stage in an attempt to achieve a more uniform utilization of the processing units.)

CHAPTER 2

MODELLING CONCEPTS

2.1. Introduction

Simulation models are constructed for the analysis of systems and subsystems, a model being defined as a formalized theory of how a system operates (9). In the present study, the models constructed cover only the manufacturing part of the total system comprising from raw material handling and storage to the marketing and distribution of the finished product.

In any simulation study, one of the most important aspects to be considered is the specification of the limitations which the models are subject to.

2.2. Scope of models constructed

The models constructed cover the activities in the process, commencing from the time the pump is switched on to the time the finished product leaves the fourth reaction stage and enters the final storage. In other words, it has been assumed that the two raw materials enter the pump in the required proportions to enable the reactions to take place in the reactors. An assumption has also been made that there is neither a loss of material nor an addition of material in any of the four reaction vessels or in the two storages in the main channels. Also, the presence of any material in the interconnecting network of pipelines and manifolds has been assumed to have no effect either on the process or on the transfer of material from stage to stage.

2.3. Criteria for evaluation of models

In developing the simulation model of this batch production process, the average percentage utilization of the various processing units, coupled with the average time spent in the units by the material, and the production rate (as determined from the total production at the termination of each simulation run) have been used as the evaluating criteria.

2.4. Flexibility and complexity of models

A simulation model serves its function by demonstrating the consequences of a particular set of inputs and decision rules applied to the process (9). In the model(s) constructed in the course of this work, flexibility of the model has been given due weight, in that the changes in the inputs and decision rules are studied with respect to the effects they have on system behavior.

As far as complexity of the model goes, the author has strived to generate a model without any complicated intricacies and avoidable details. Any attempt to limit the complexity of simulation models puts a limit on the number of factors considered and their effects on the system, which are the system responses (2). As a result, the first model constructed is simple and straightforward, with the possibility of incorporating changes, refinements and modifications.

2.5. Programming language used

Complex mathematical tools can be made use of in constructing models of manufacturing systems and processes. However, at times, the effort involved in this approach is quite discouraging and there are cases wherein it may not be possible to obtain a solution. Simulation can be adopted as a technique to overcome these drawbacks effectively.

Simulation is the use of a model to study a system. It is a numerical technique for conducting experiments with certain types of mathematical and logical models, describing the behavior of the system on a digital computer over extended periods of time (11).

In this simulation study, GPSS/360 (General Purpose Simulation System/360), has been used as the programming language. This is a simulation program developed and maintained by IBM for their 7040/44, 7090/94 and the 360 series of computers. The language is structured to facilitate programming from block diagrams which pictorially represent the flow of materials through the system being simulated. The language is described in brief in the following paragraphs.

The block diagrams, which are used to describe the structure of the system, consist of a series of blocks, each of which describes some particular step in the action of the system. Alternative paths or courses of action are easy to provide in GPSS/360 and may be based on a probabilistic event or a logical choice, depending on the state of the system at that time. There are forty-three block entities associated with GPSS, each being associated with a set of actions to be performed on the transactions.

"Transactions" are the units of traffic which move through the system. These may be, depending on the system being simulated, communication messages, electrical pulses in a circuit, work items in a production line. In this study, transactions represent the material which flows through the four reactors to form the final product at the end of the fourth reactor. The GPSS/360 program also has entities known as facilities, storages, queues, tables, etc., whose attributes are changed appropriately by the movement of transactions through them.

Therefore, using GPSS/360, a completely self-contained simulation program can be formulated, in which the program is capable of generating all the input information required for the model. This is achieved using a number of specified statistical distributions, functions and variables. If needed, special statistics can be defined and gathered at any stage of the system.

CHAPTER 3

DEVELOPMENT OF MODEL 1 OF CONFIGURATION 1

The following pages describe the manner in which the first model of the existing configuration is constructed. The GPSS/360 block diagram for this model is given in Figure 3.2. For the sake of convenience and lucidity, the block diagram has been split into a number of subsections. The part of the process pertaining to the particular subsection of the block diagram is also provided alongside.

3.1. Procedure for building Model 1.

The process as a whole can be subdivided into the following six stages:

1. Generation of the material to be processed;
2. Gathering operations at the first level holding tanks 1 and 2;
3. First and second stage reactions;
4. Third stage reaction;
5. Intermediate storage in the second level holding tanks 3 and 4; and
6. Entry into the final storage.

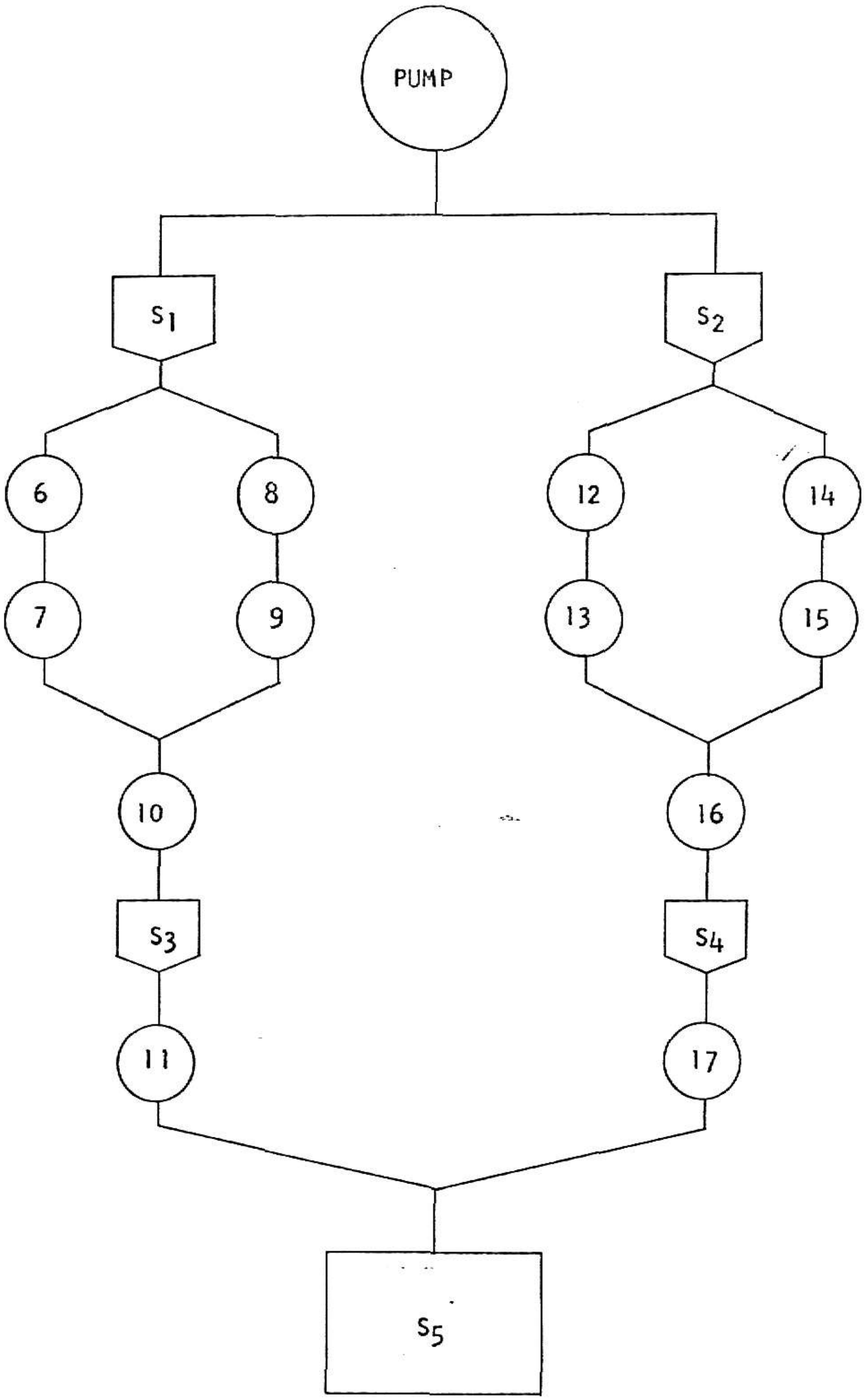


Figure 3.1. Configuration 1, Model 1.

The simulation is commenced on the assumption that all the facilities and holding tanks in the system are unoccupied at the start. The pump, which sends the material to the two main channels, works on a continuous basis at the rate of 8 pounds/hour. As has been mentioned earlier, the twelve processing units have a capacity of 7 pounds each, and the four holding tanks have a capacity of 14 pounds each. For the purposes of this study, an equivalence has been drawn between 1 hour of real clock time and 600 units of simulation clock time. Also, one transaction is taken to have a weight of 1 pound of the material being processed. Since there is no loss of material at any intermediate point of the process, the transactions that enter the final storage also represent the total production. Each of the six stages is described in brief.

3.1.1. Generation of the material.

The mixture of the two raw materials arrives at the rate of 8 pounds/hour. In other words, the pumping rate is 8 pounds/hour. This is achieved by providing a GENERATE block to generate one transaction at the end of every 75 simulation time units. The transactions have fullword parameters associated with them.

3.1.2. Gathering operations at the first level holding tanks.

The GENERATEd material arrives at a multiple function valve which directs the flow of the material along one of three routes, two of them leading to one or the other of the two holding tanks and the third leading to the TERMINATE block, which removes the transaction from the system. The left hand side of the system has been favored over the right hand side in the selection of the paths from the pump. The functions of the multiple function manifold valve are adequately performed by the TRANSFER block with an ALL mode. This causes the transaction to attempt an entry into the left hand holding tank, the right hand holding tank and, if neither path is open, the TERMINATE block, which never refuses entry to a transaction.

If, however, a transaction succeeds in getting into a holding tank, the material accumulates in the tank and does not proceed to the next unit in the line (the first stage reactor) unless the contents of the tank have a weight of 7 or 14 pounds. The function of the TEST block is to test whether the contents of the tank have a weight of 7 or 14 pounds. If not, the transaction is terminated in the TERMINATE block. If the contents of the tank have a weight of either 7 or 14 pounds the material attempts to move into the first stage reactor, leaving the holding tank with a weight of 7 pounds. The transfer of material from unit to unit is on a bulk basis and has been assumed to occur instantaneously.

3.1.3. First and Second stage reactions.

The arrangement of the units in the two sides of the system is identical and hence it will not be necessary to follow the progress of the material (the transactions) in both sides of the system. The transaction at the exit from the holding tank can

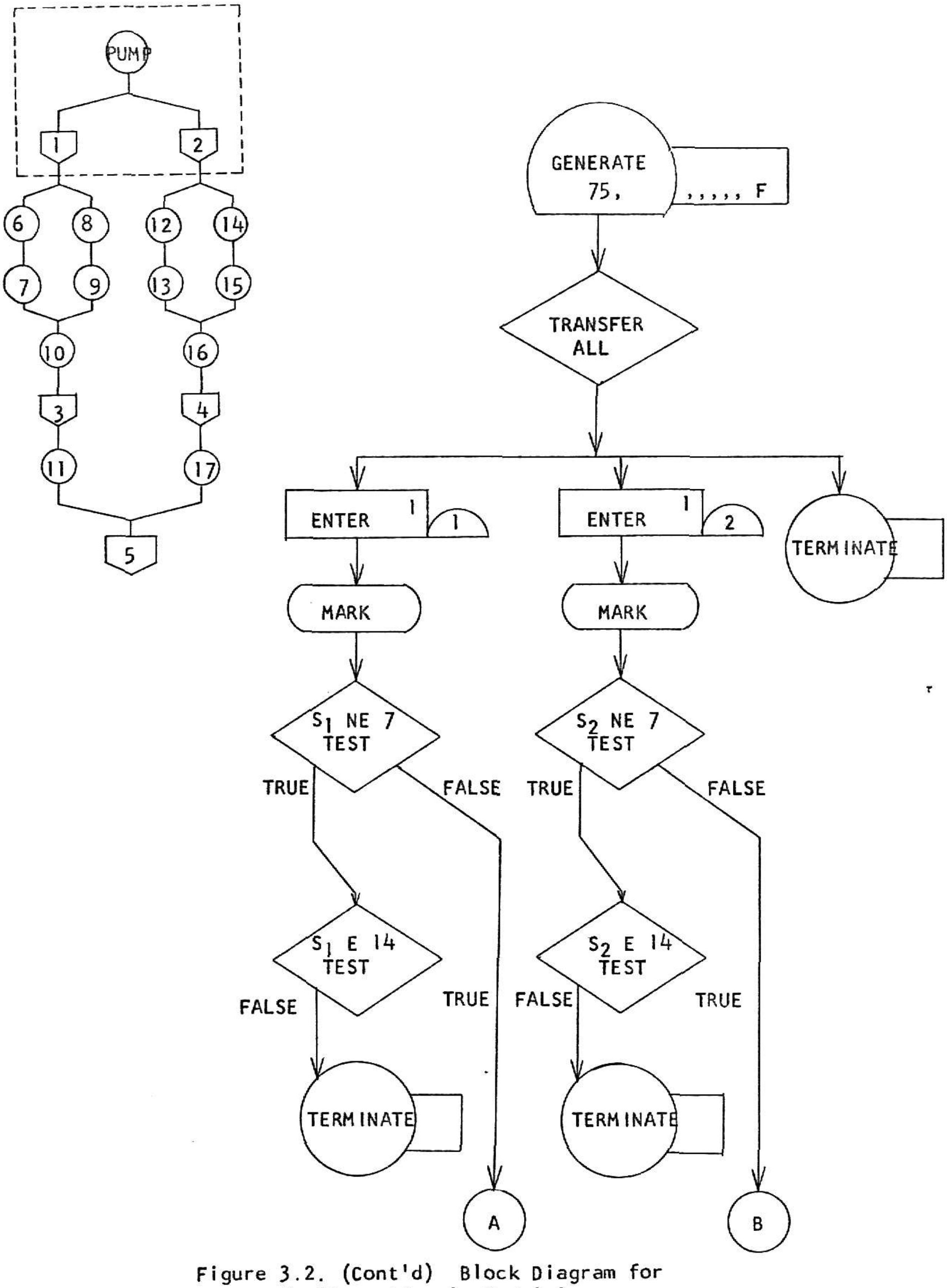


Figure 3.2. (Cont'd) Block Diagram for Configuration 1, Model 1.

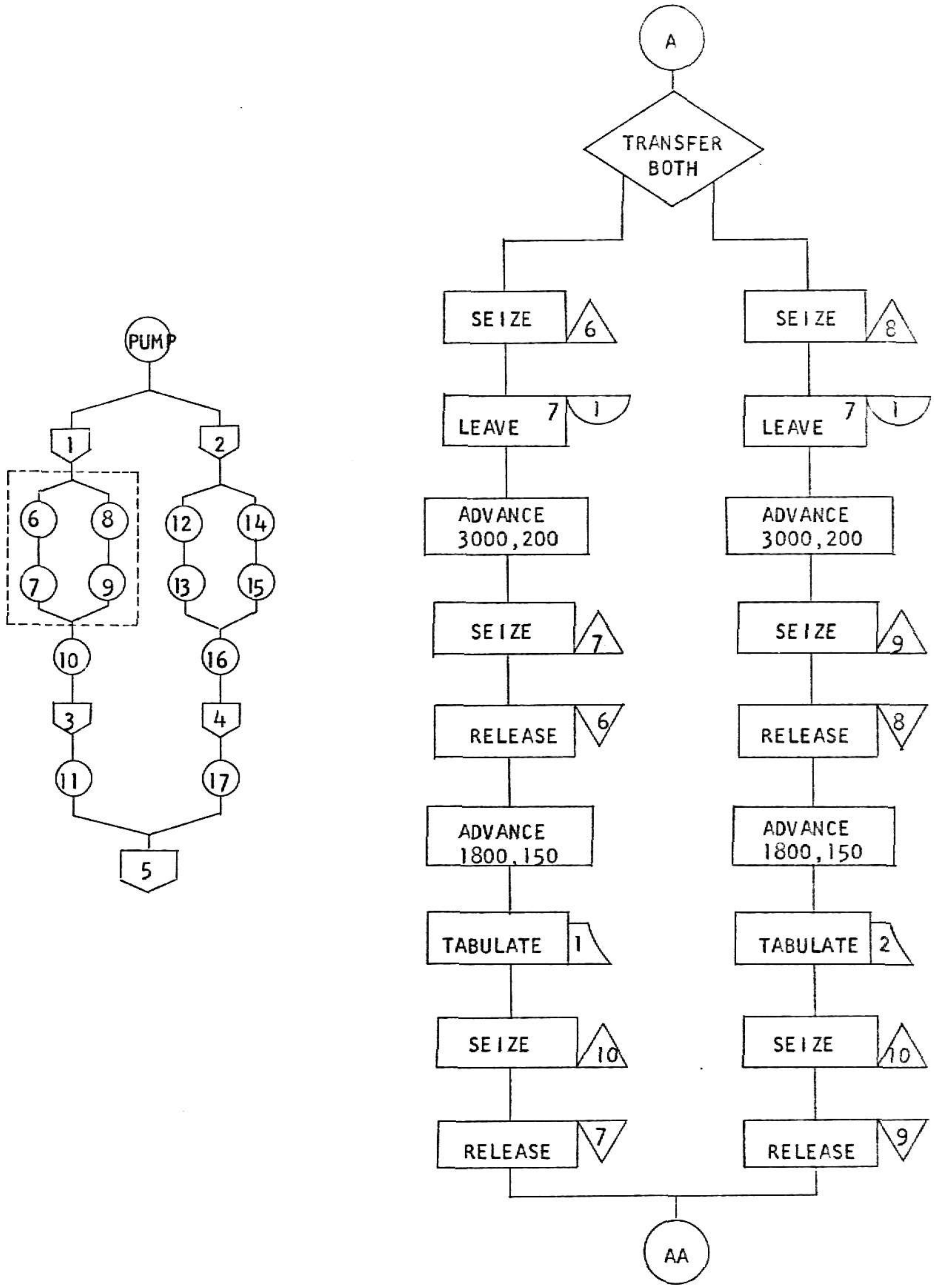


Figure 3.2. (Cont'd)

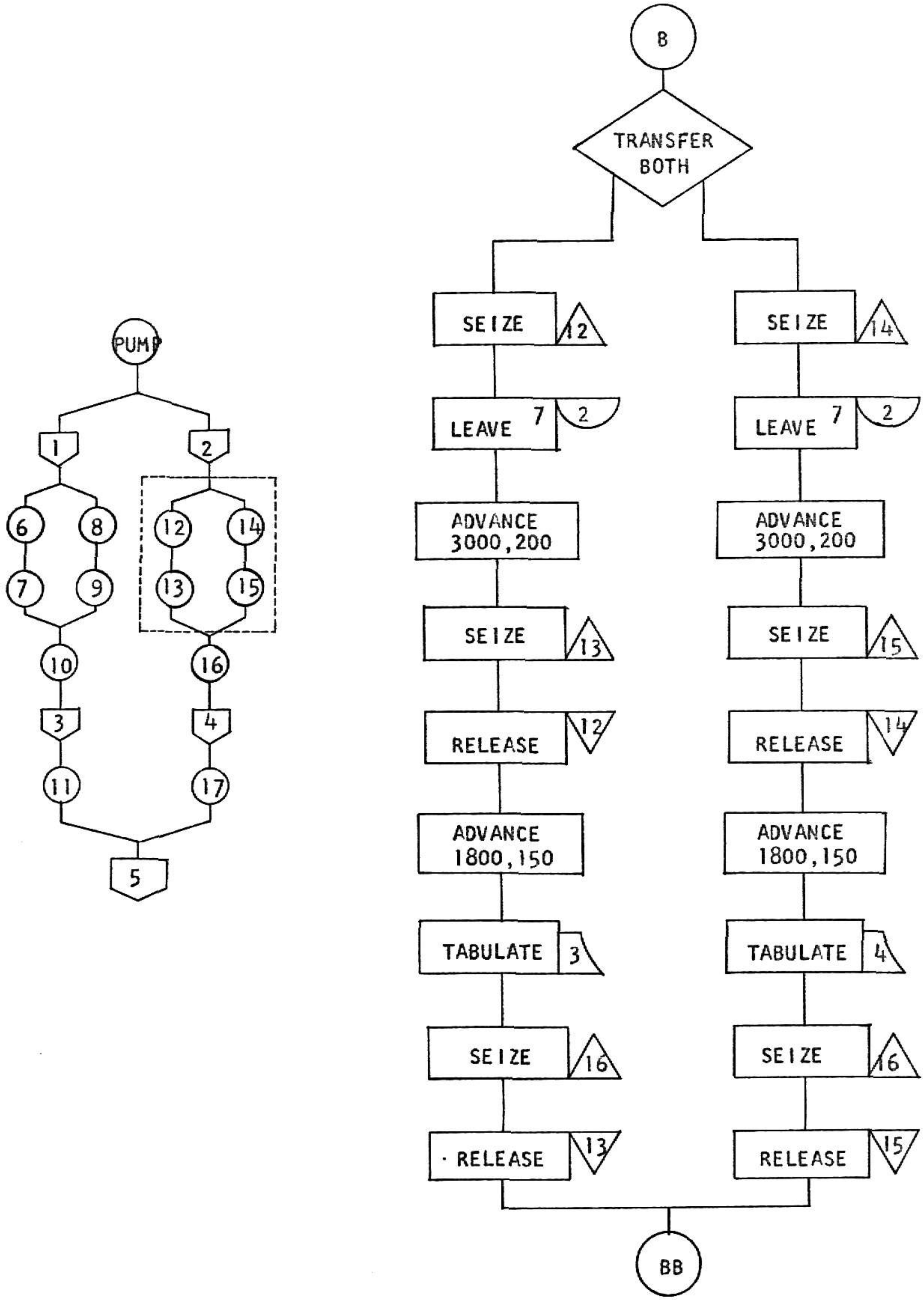
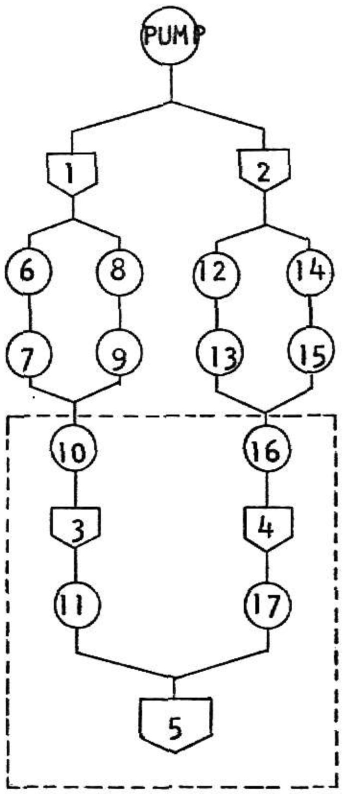


Figure 3.2. (Cont'd).



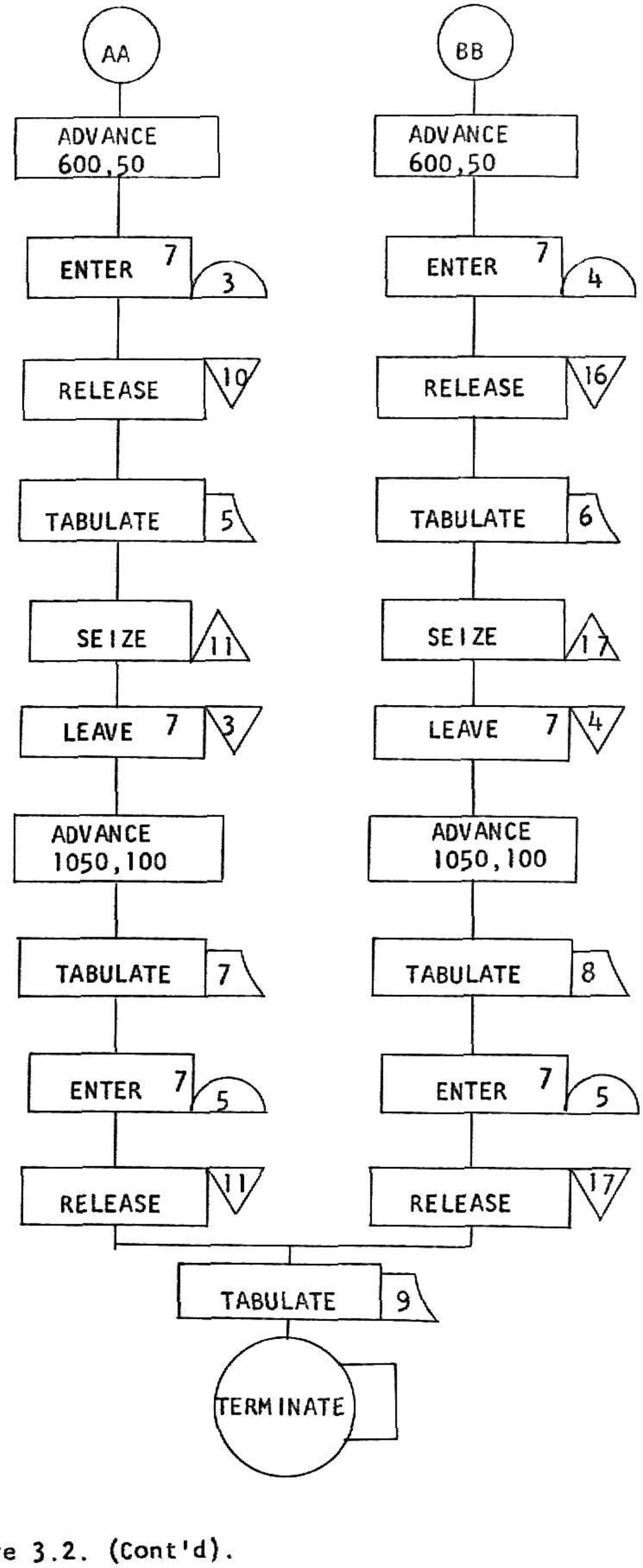


Figure 3.2. (Cont'd).

attempt to occupy either of the two reactors at the first stage. In order to maintain a certain consistency in the modelling, a priority has been given in favor of the left hand reactor. Once a reactor has been occupied by the material from the holding tank, the processing is assumed to commence immediately. The ADVANCE block performs the function of advancing the absolute and the relative clock times by the processing time at this reactor. The processing time is selected by GPSS/360 from the range of 3000 ± 200, wherein all the numbers have an equal probability of being selected. On completion of processing at the first stage, the material attempts to occupy the second stage reactor in that line, since this configuration allows the first stage reactor to discharge its contents into the immediately following unit in that particular line. This means that if the latter is occupied, the first stage unit cannot empty its contents. However, this contingency is not likely to arise because the second stage reaction time is considerably lower than the first and any delay here is most likely to be very small.

Once the second stage reactor has been occupied, processing commences and lasts for a time as selected by GPSS/360 within the range 1800 ± 150 on an equal probability basis. When the processing has been completed, the material attempts to move into the third stage reactor.

3.1.4. Third stage reaction.

There is only one unit at the third stage and the two subchannels direct the material into this one unit. Also, because the left hand side has been consistently favored over the right hand side, the material flowing along the subchannel on the left occupies the third stage reactor first. The processing time at this stage being only 600 ± 50 simulation time units, it is reasonable to expect small delays, if any. The processed material from the third stage reactor proceeds to occupy 7 units of storage in the holding tank at the second level.

3.1.5. Intermediate storage at second level holding tank and final reaction.

The second level holding tank has a capacity of 14 pounds and, if storage space is available, the contents of the third stage reactor will be "dumped" into this tank. On successful entry into this intermediate storage tank, the material immediately attempts to occupy the fourth, and final, reactor. If a certain amount of delay is present prior to occupying the reactor, and it is very possible for such a delay to be present, the material will remain in the holding tank till the final processing unit becomes available. Immediately after it is full, the material is processed and emerges from it as the finished product.

3.1.6. Entry into the final storage.

The finished product emerging from the fourth stage reactor enters the final storage without any delay. This is acceptable because the capacity of this storage has been assumed to be very large.

3.2. Data on system performance.

The GPSS/360 output editor provides the results from the simulation in the form of distribution tables, queue statistics, storage statistics and facility statistics as part of the standard output obtained at the end of every simulation run. In this study, frequency distributions of the transaction transit times from the time of entry into the holding tanks at the first level to the end of each reaction stage. This is achieved by providing the GPSS block TABULATE. This refers to a particular table previously defined. Whenever a TABULATE block is encountered, the table referred to is printed, along with the mean and standard deviation of the entity being tabulated.

The storage and facility statistics are part of the standard GPSS output and provide information on average unit utilization and average, current and maximum contents of all holding tanks. The blocks and block entry count are also printed as part of the standard output.

In this model, there are four lines till the end of the second stage and frequency distribution tables of transit times are obtained for each line. In each side of the system, TABULATE blocks are also provided at the end of the third and fourth stages and immediately prior to entering the final storage. These data were gathered over a run of 660000 simulation clock units or, in equivalent real time, 1100 hours, at the end of every 100 hours. From initial experimental runs, it was found necessary to run the

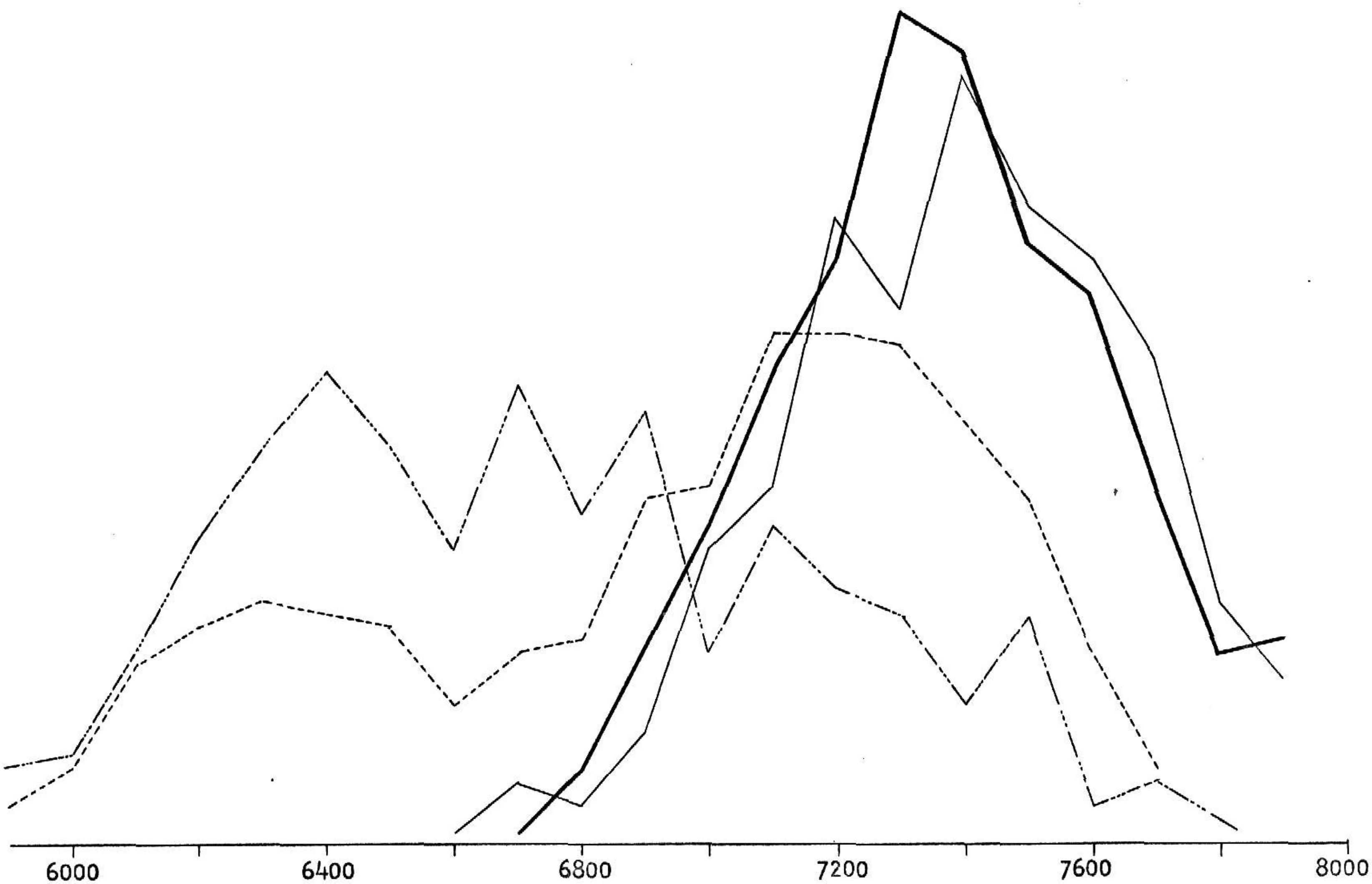


Figure 3.3. Distribution of Transit Times at End of Second Stage in the Four Lines in Configuration 1, Model 1.

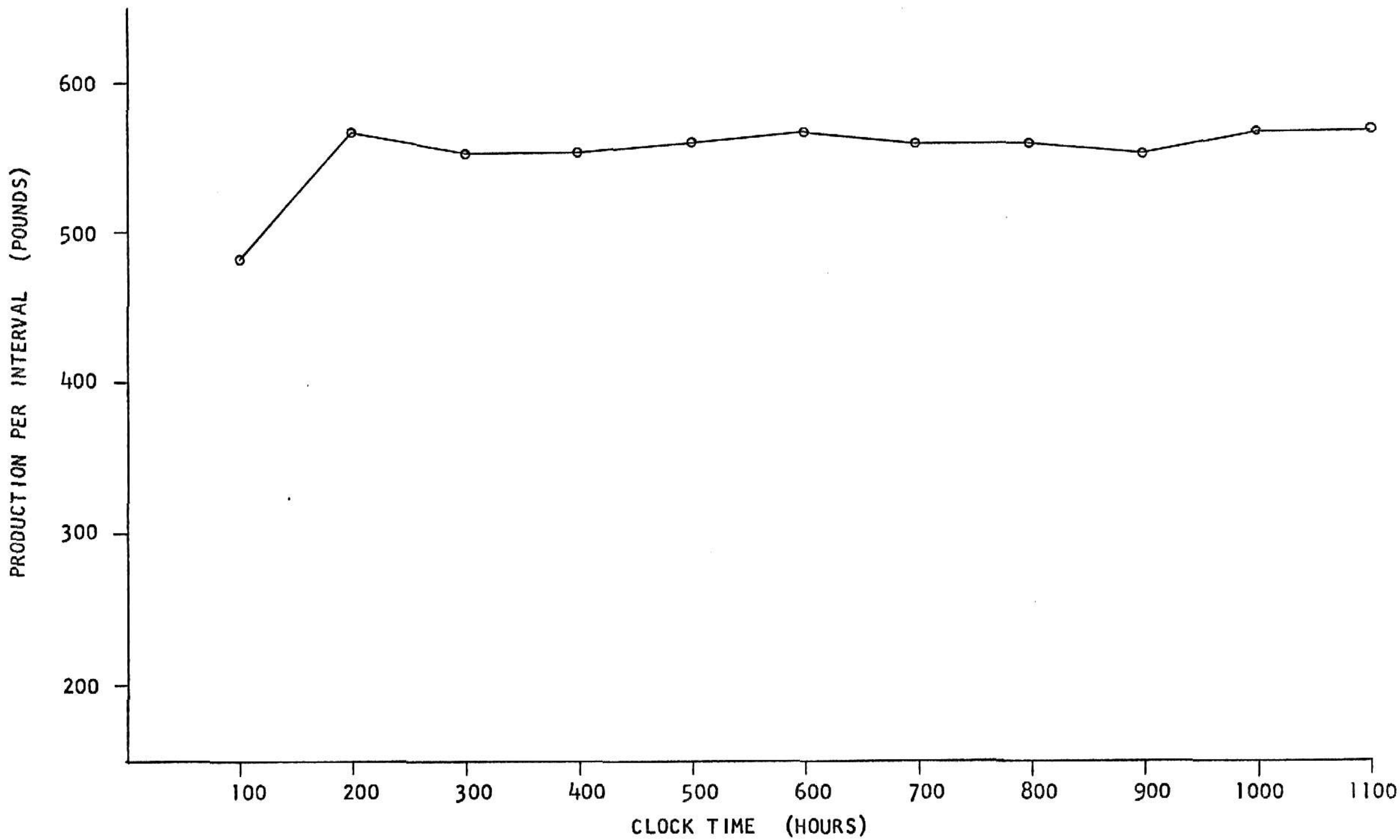


Figure 3.4. Production Per Interval of 100 Hours. Configuration 1, Model 1.

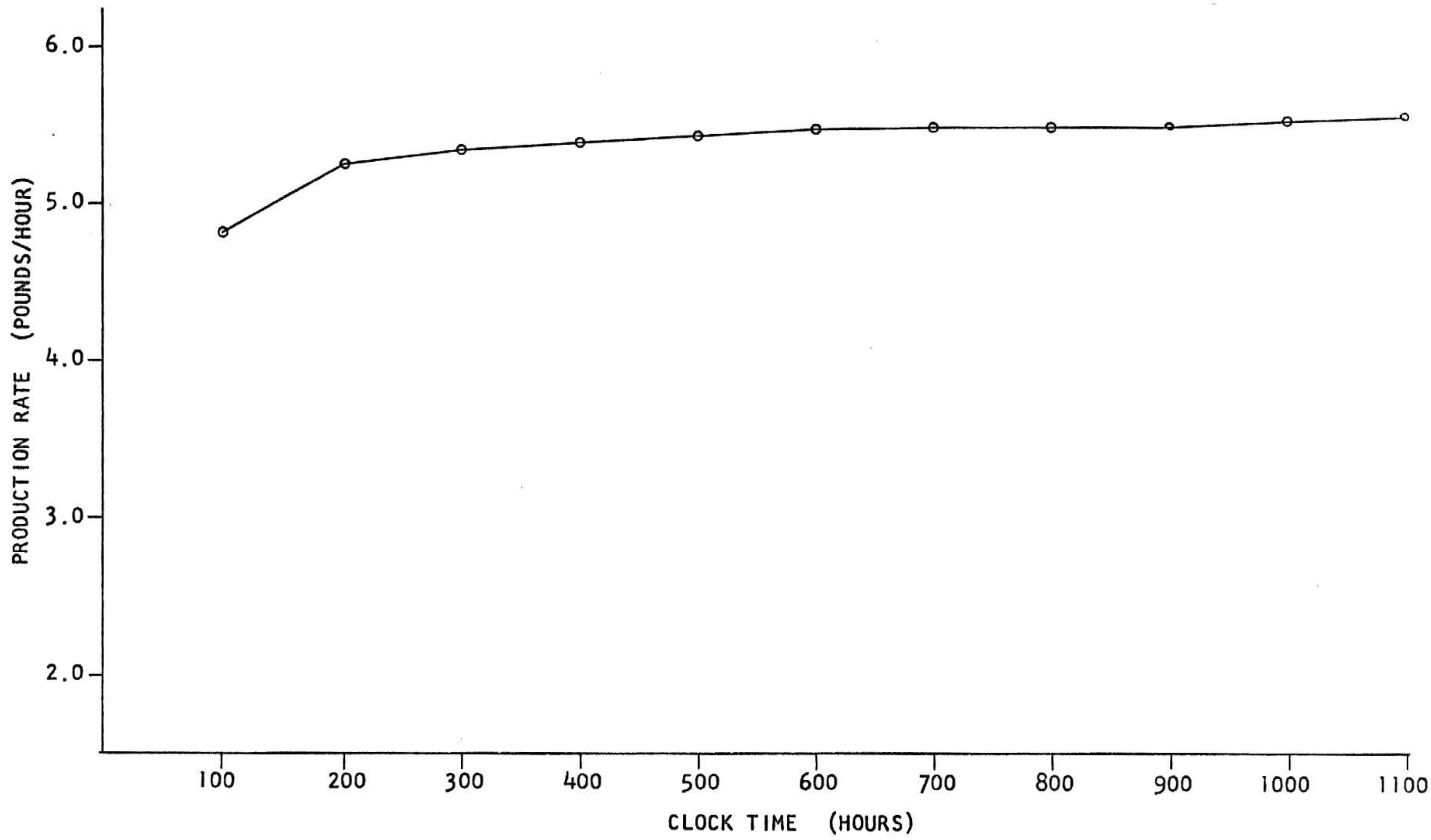


Figure 3.5. Production Rate for Configuration 1, Model 1.

system for about 200 hours before it reached a steady state. In order to obtain simulation data after stabilization, it was decided to extend the run duration to a total of 1100 hours. The run procedure adopted in all the models studied has been to reset the relative clock time to zero after 100 hours of operation and then run the simulation for 1000 hours, the simulation data being outputted every 100 hours.

The first stage reactors show a consistently higher utilization factor than the corresponding second stage reactors in the same line. This is understandable because the processing time in the first stage reactor units is, on the average, 1200 simulation clock units (2 hours, real clock time) longer than that in the second stage units. This rather large difference causes the latter to wait for a considerable period of time prior to getting charged with fresh material. The same holds good for the relatively low utilization of the third stage reactor units. The final stage has a slightly higher factor of utilization due to the processing time associated with it being on the average, 75 per cent longer than that of the third stage reactor units.

Regarding the storage statistics, what is of greater significance than the utilization factors is the number of entries and the maximum contents. The former is an indication of how many transactions passed through the storage unit and can be used to compare corresponding units in the two main production lines. This may also help detect the presence of bottlenecks in the process, if any. The maximum contents, especially that of the final storage, gives the accumulated weight of the material and the maximum contents of the final storage gives the total production at the end of a simulation run. Figure 3.6 shows the configuration being simulated, along with the average utilizations of the twelve facilities and four storages.

Figures 3.3, 3.4 and 3.5 are in turn the plots of the frequency tables obtained at the end of the second stage in the four subchannels, the production per interval of 100 real clock hours and the production rate in pounds per hour at the end of every 100 hours, with the pump working at 8 pounds/hour.

Figure 3.3 shows, for a pumping rate of 8 pounds/hour, the frequency distribution of the transaction transit times in the four lines till the end of the second stage. There is no distinct peak in either of the two lines on the left side of the system and the mean transit times in these two lines are 6940 and 7212 simulation clock units. Also, there is a marked delay in the flow through the right side of the system, as seen from the range of the transit times in these two lines. This can be attributed to the initial bias given in favor of the left hand side of the configuration. In the following chapter, this model is refined and modified to eliminate these inconsistencies.

The critical section of the system, as far as the production of the finished product is concerned, is the first stage reactor vessels. This is understandable because the processing time here

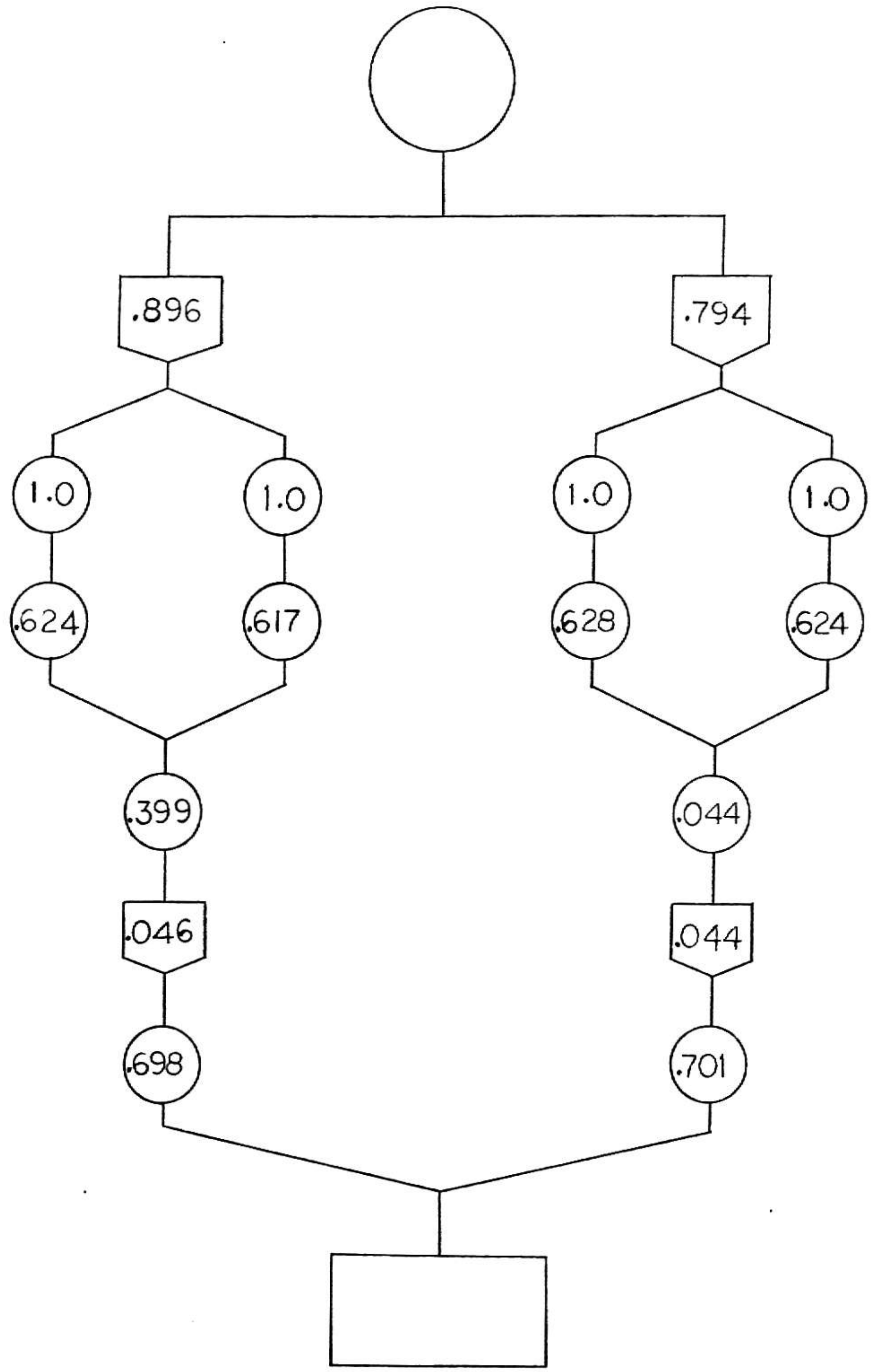


Figure 3.6. Configuration 1, Model 1,
Showing Average Utilization of the Equipment.

is the longest of all. This, therefore, sets an upper limit on the rate of production. The following simple arithmetic shows what this is.

$$\text{Maximum production rate} = \frac{(\text{No. of I stage reactors})(\text{Capacity of each})}{\text{Processing Time at I stage}}$$

$$= \frac{4 \times 7}{5} = 28/5 = 5.6 \text{ pounds/hour}$$

The theoretical maximum production rate is, therefore, 5.6 #/hour.

One way to evaluate the performance of the simulated system is to compare it with the theoretical performance. A criterion of evaluation is the actual production capacity and how it compares with the theoretical capacity. After the system settles down to a steady output, the production rate is 5.5 pounds/hour. This compares quite favorably with the theoretical maximum of 5.6 pounds/hour. This also, to a certain extent, bears out the validity of the simulation model in that this model is behaving quite predictably, subject to its inherent shortcomings.

CHAPTER 4

REFINEMENTS ON MODEL 1 OF CONFIGURATION 1

The discussion of the data obtained from the simulation of Model 1 indicates the need for the removal of the nonuniformity of production rates in the two sides of the process which are otherwise functioning normally.

4.1. Modifications introduced.

4.1.1. Change in mode of operation of pump.

The very first change in approach effected was the use of the pump only when it was necessary. Thus, whereas in Model 1 the pump was a pulsed generator of material, it is considered in Model 2 as another facility, on a par with the reactor units. The pump is therefore "switched on" whenever any one of the four first stage reactors is charged with fresh material. This "switching on" operation is described in some detail after the gathering operations at the first level holding tanks.

The present mode of operation of the pump helps eliminate a major drawback which existed in Model 1. Whereas in the first model studied, the filling of holding tank 2 was interrupted whenever holding tank 1 was not full, in the present model, the two tanks receive material from the pump on an equal probability basis.

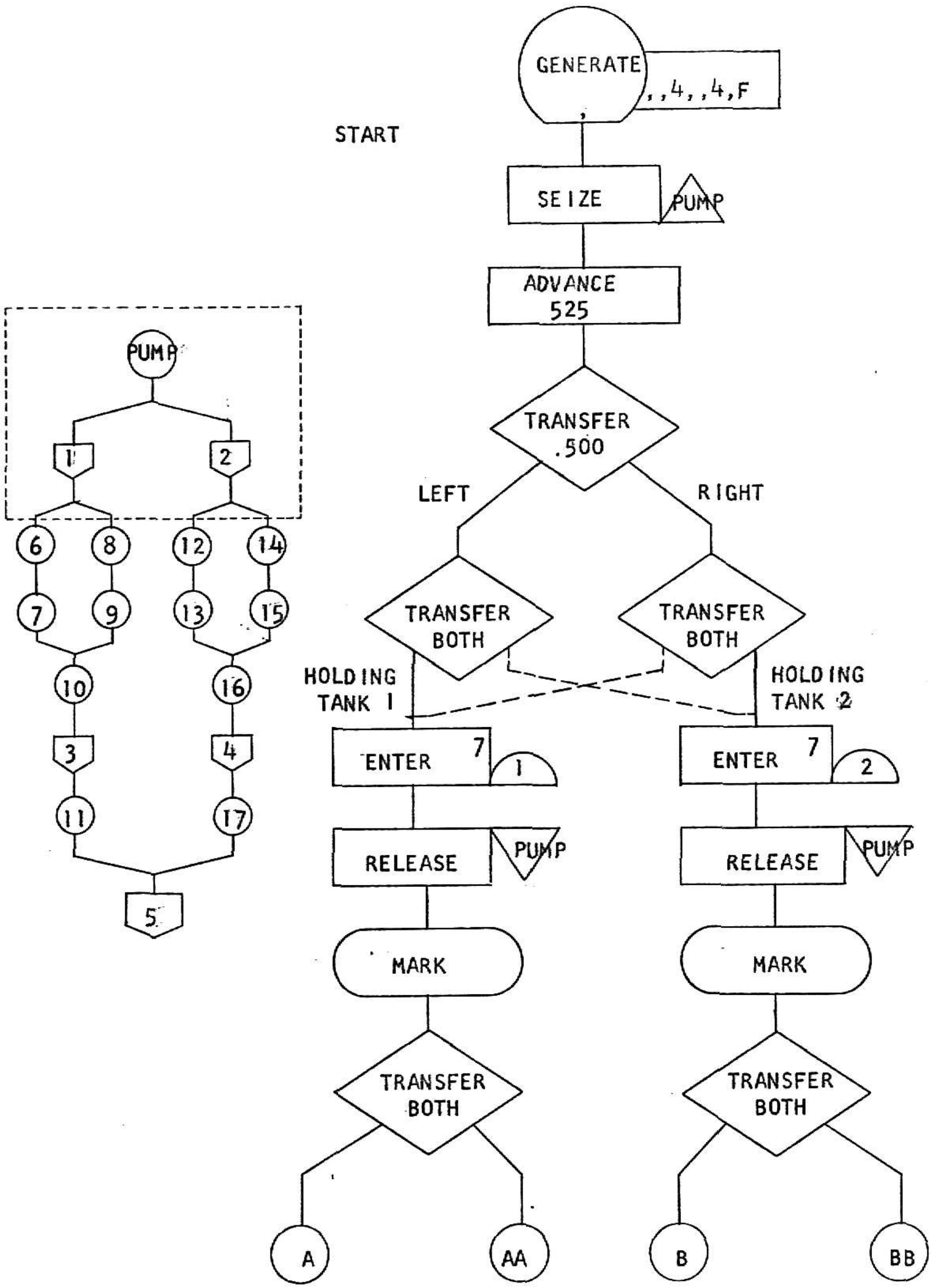


Figure 4.1. GPSS/360 Block Diagram for Configuration 1, Model 2.

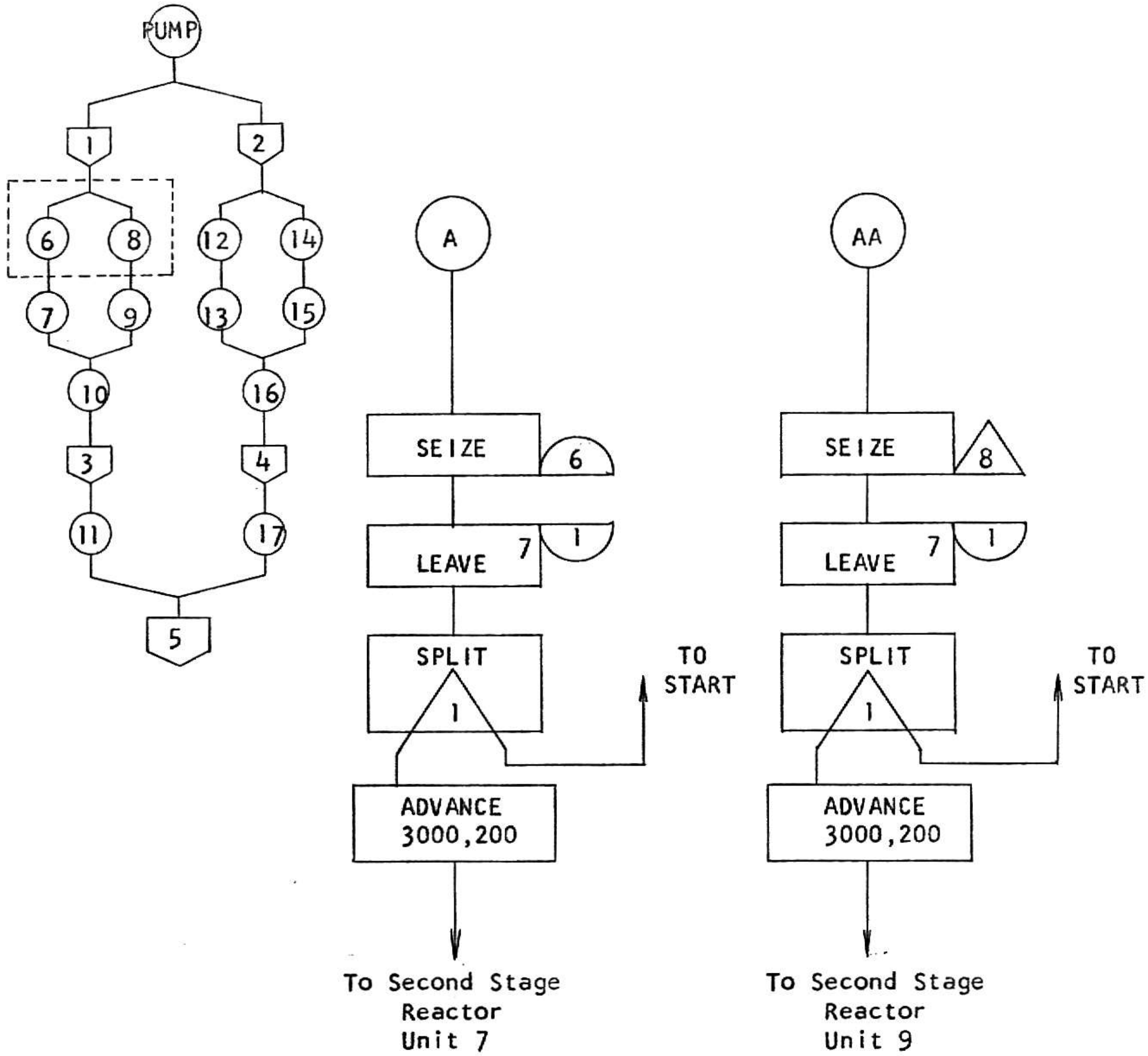


Figure 4.1 (Cont'd). GPSS/360 Block Diagram for Model 2. The rest of the block diagram is similar to that of Model 1, shown in Figure 3.2.

Also, considering the pump as a facility, results in obtaining more accurate information on the pump utilization.

4.1.2. Probabilistic transfer of material.

In order to start the simulation, four transactions are created simultaneously at the GENERATE block (see Figure 4.1). The pump, as a facility, is SEIZEd by a transaction, which has a weight of 7 pounds. The pump is in the possession of this transaction for a period of time equal to that required to send 7 pounds of material into one of the two holding tanks. At the end of this time (which is 525 simulation clock units corresponding to a pumping rate of 8 pounds/hour) the transaction, representing 7 pounds of the mixture of the two raw materials, moves into the holding tank. The selection of one tank out of the two is made by GPSS on a probabilistic basis, with both tanks having an equal probability of being chosen. If, however, the path so selected leads to a tank already full, the other tank will be tried. This mode of gathering eliminates the bias introduced into Model 1.

The difference in the manner of operation of the pump is achieved by including one more GPSS/360 block prior to the first stage reaction. This is the SPLIT block which creates copy transactions. Sequentially, the ADVANCE block follows immediately after the SPLIT block. When the first stage reactor is occupied by the material from the holding tank, the SPLIT block creates an offspring transaction identical in every respect to the original and sends it back to the pump. This copy transaction SEIZEs the pump

TABLE 4.1 A Comparison of Mean Transaction Transit Times at Various Points in the Process*
(In Simulation Time Units)

Point Where Table Statistics are Obtained	MEAN TRANSIT TIME (In Simulation Clock Units)	
	MODEL 1	MODEL 2
At End of Stage 2:		
Line 1	6858	7043
Line 2	7024	7061
Line 3	7270	7198
Line 4	7154	7059
At End of Stage 3:		
Left Side	7939	7744
Right Side	7524	7754
At End of Stage 4:		
	8929	8924

* For a pumping rate of 8 pounds/hour.

and after an interval of 525 simulation time units, enters one or the other of the two holding tanks. The improvement due to this modification can be seen in the utilization of the pump at the end of 1100 hours, which is 0.703 or 70.3 per cent.

The provision of material transfer on the basis of a probabilistic choice of alternative paths of flow has a very significant consequence. This is apparent in Figure 4.2 which shows a very distinct similarity in the frequency distribution of the transit times at the end of the Second Stage reaction in the four lines. This is due to the removal of the favoring given to the left hand side in Model 1. A comparison of mean transit times till the end of the second stage in the two models is shown in Table 4.1.

Figure 4.3 gives the production rates in pounds/hour in the two models at the end of every 100 hours for a simulation run of duration 1100 hours. There is a marked improvement in the production rate in Model 2 over that in Model 1.

The simulation was performed with different pumping rates and the distribution of the transit times till the end of the second stage at a pumping rate of 6 pounds/hour in the four lines is shown in Figure 4.4. The system was simulated at pumping rates of 4 #/hour, 5 #/hour and 5.5 #/hour also. The production at these pumping rates was distinctly lower than that at 8 pounds/hour and did not encourage investigation into the data obtained. The distinctly lower production at these pump rates can only be attributed to the additional time taken in providing enough material to fill

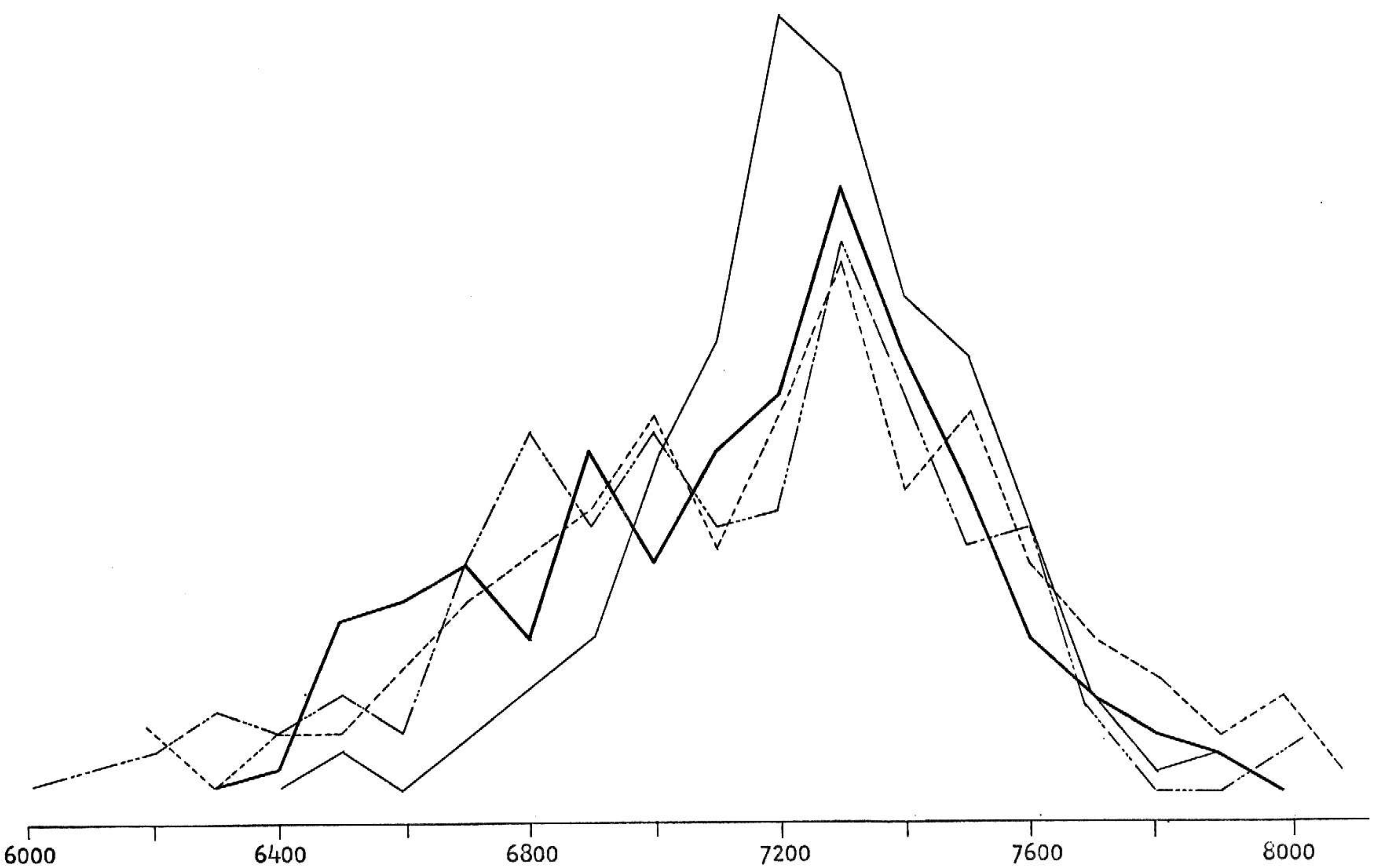


Figure 4.2. Distribution of Transit Times at the End of Second Stage in the Four Lines in Configuration 1, Model 2.

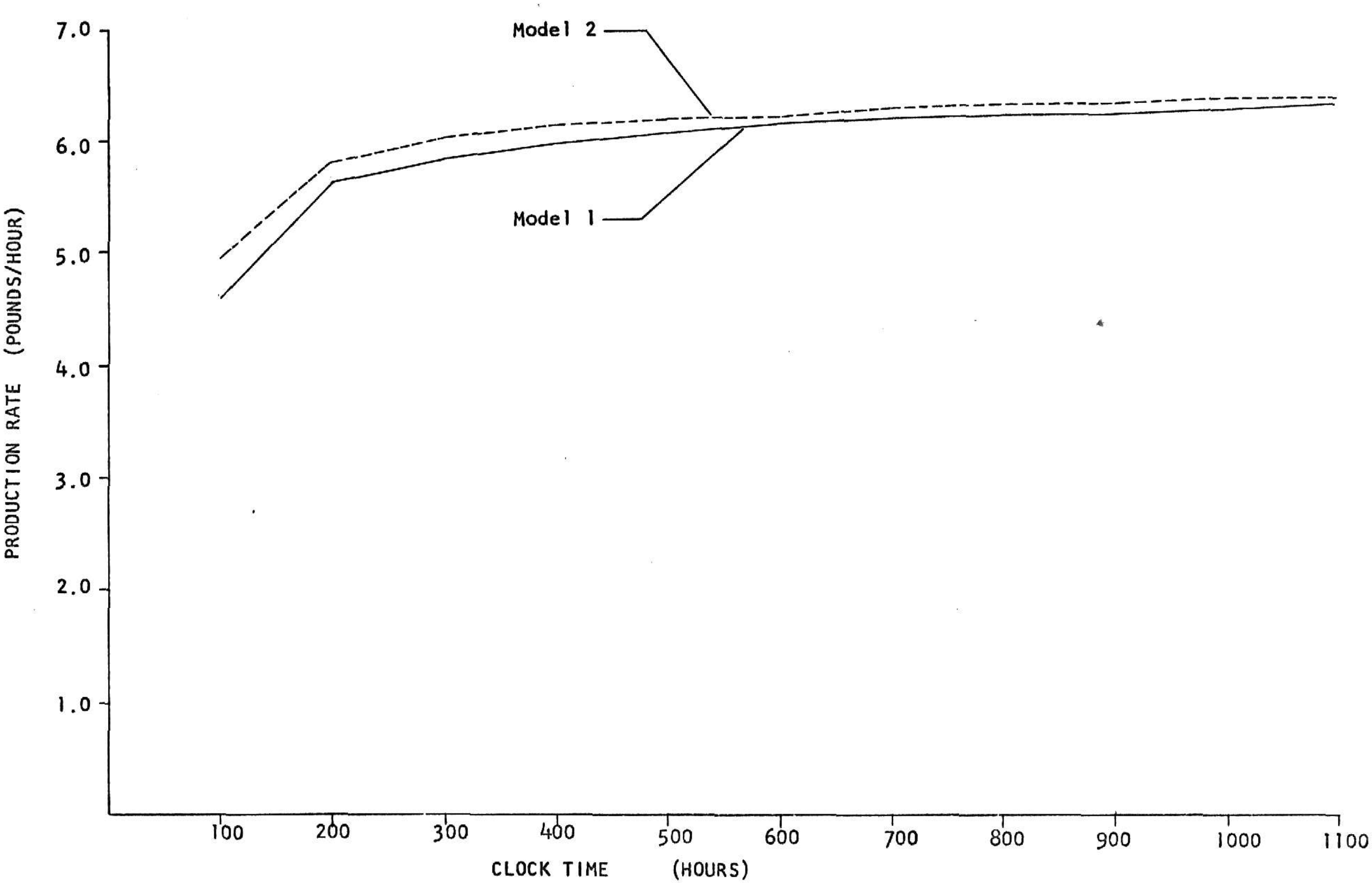


Figure 4.3. A Comparison of Production Rates in Models 1 and 2, at a Pumping Rate of 8 Pounds/Hour.

the first stage reactors. There was not any appreciable increase in either the total production or the production rate when the pumping rate was increased from 6 pounds/hour to 10 pounds/hour. This can be seen in Figure 4.5. Consequently, the effect of running the pump at higher pumping rates was not investigated.

Figure 4.6 shows the arrangement of the processing units and holding tanks for this model and the average utilization factors of these units at the end of 1100 hours, real clock time, or 660000 simulation clock units. A comparison of the average utilizations of the first stage and the second stage reactors in the two models so far constructed does not show any appreciable difference. There is, therefore, still room for further refinement and improvement.

The storage statistics, printed out as part of the standard GPSS/360 output, indicate that the maximum contents of the holding tanks at the second level (between the third and the fourth stage reactors) never exceeded 7 pounds throughout the simulation run. This shows that the holdings tanks have been provided with twice the necessary capacity. Holding tanks of 7 pounds capacity would have served equally efficiently.

It was also found that using different random number seeds did not have any appreciable effect on the simulation results. There was, however, a slight difference in the results when using different seeds which can be classified as an experimental error. A small sampling error indicates a stable model that is insensitive to

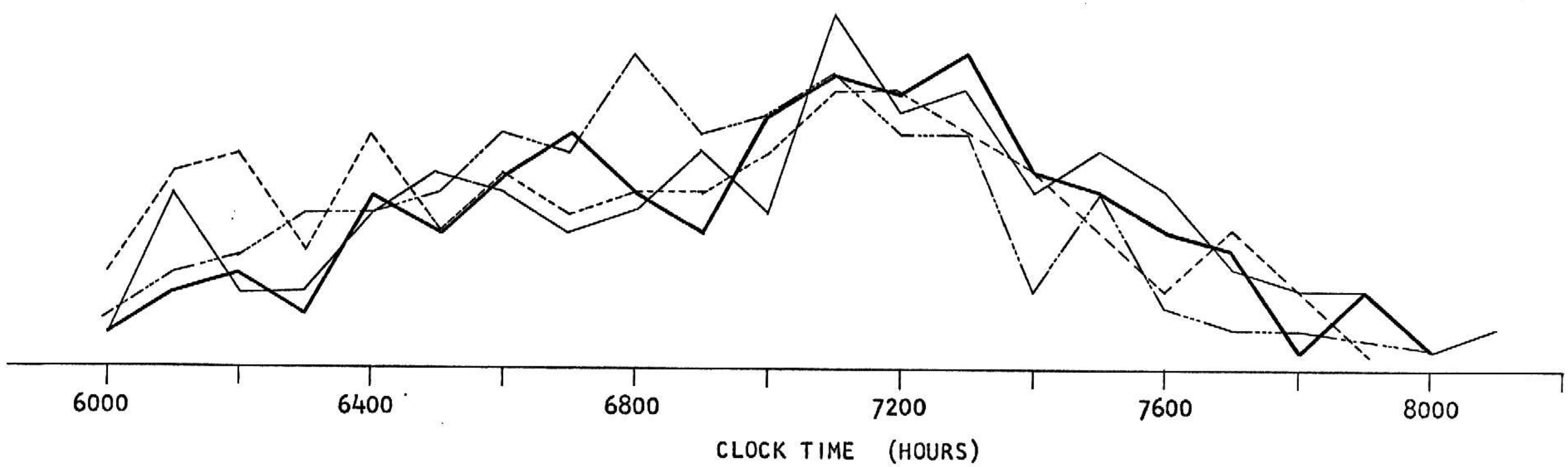


Figure 4.4. Distribution of Transit Time in the Four Lines at the end of Second Stage in Configuration 1, Model 2, at a Pumping Rate of 6 Pounds/Hour.

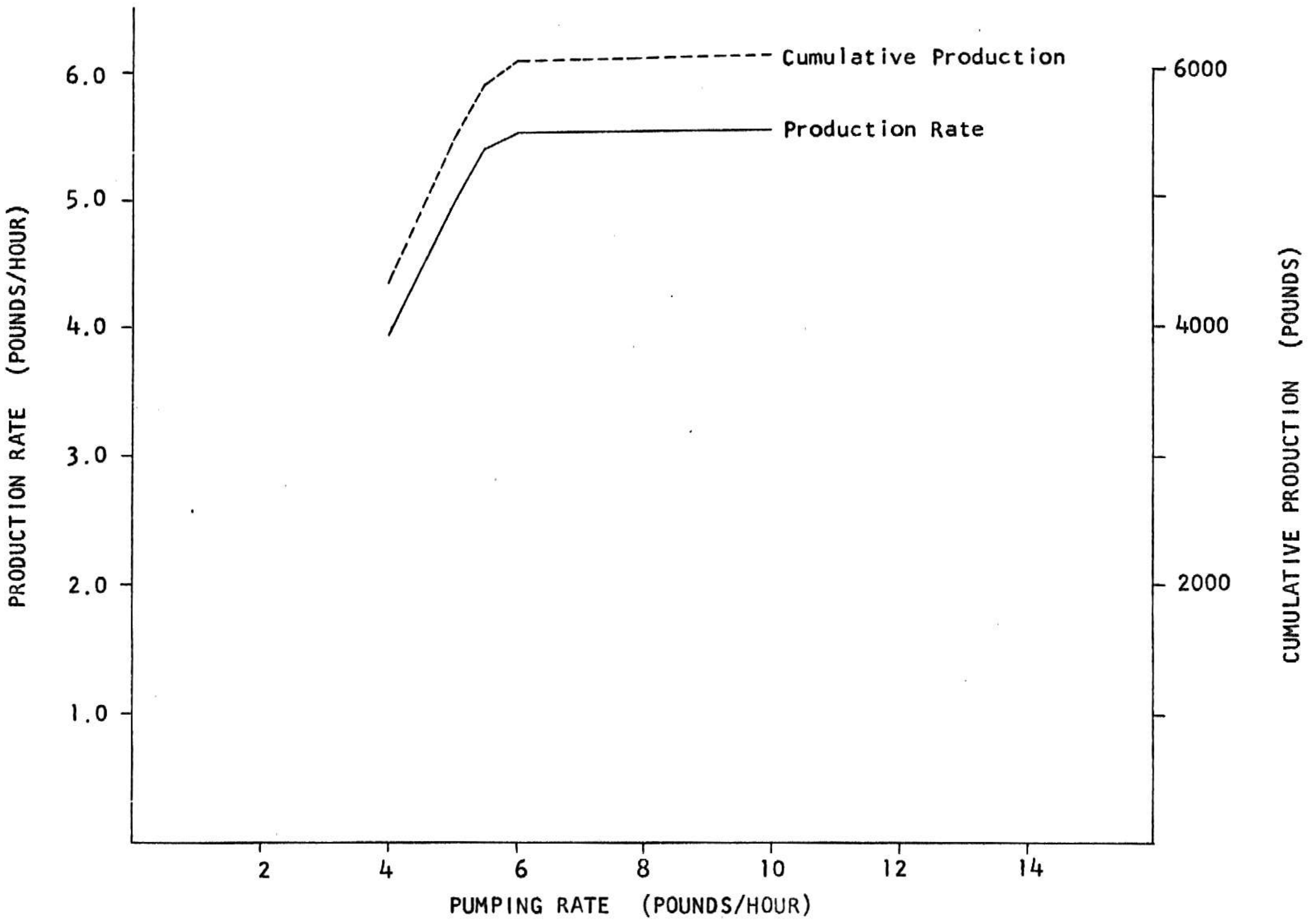


Figure 4.5. Effect of Varying the Pumping Rate on Cumulative Production and Production Rate (Configuration 1, Model 2).

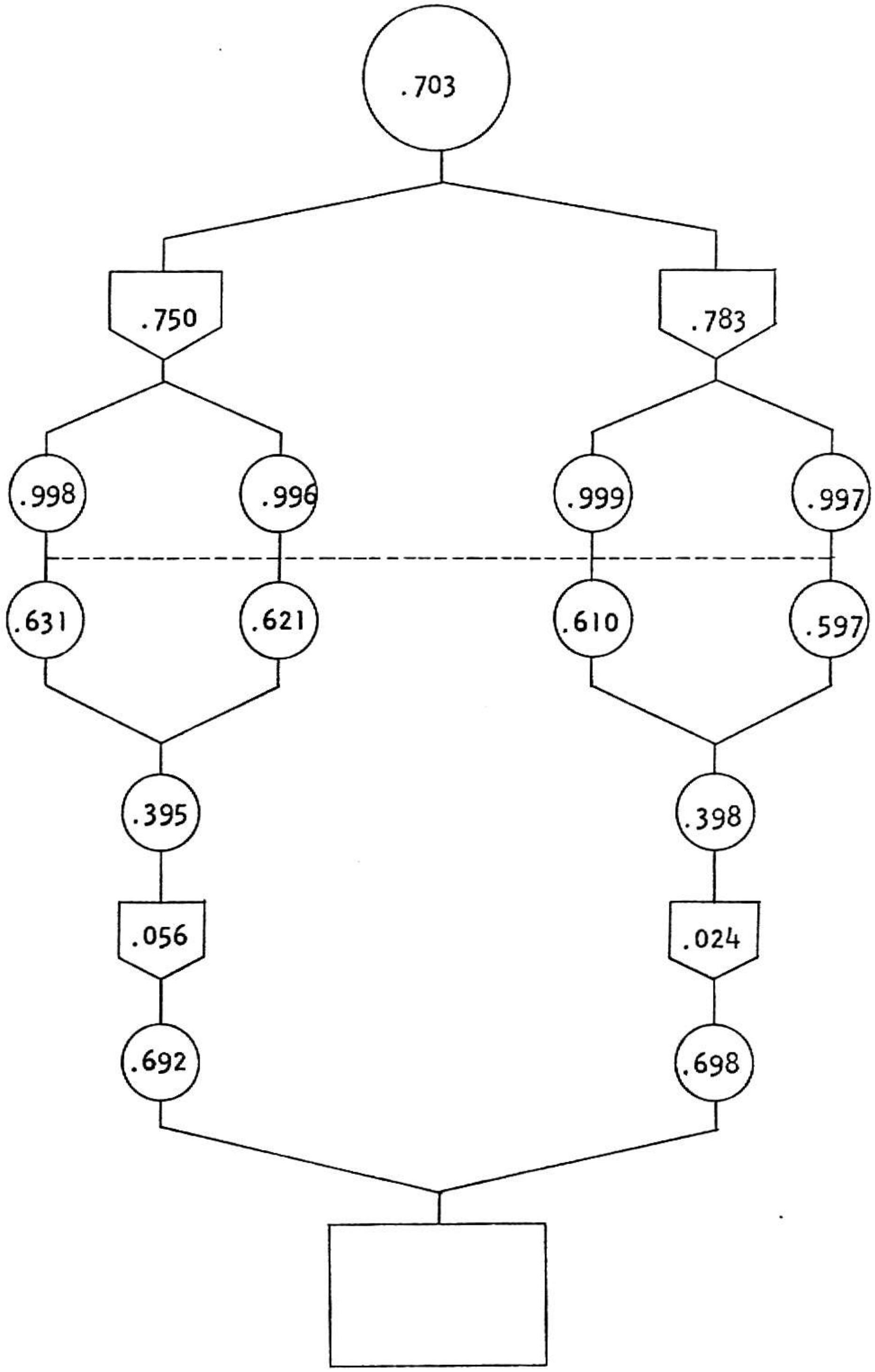


Figure 4.6. Average Utilization of Equipment in Configuration 1, Model 2, at a Pumping Rate of 8 Pounds/Hour.

stochastic perturbations. Table 4.2 gives a comparison of the results obtained from simulation runs using different seeds for the random number generators.

An attempted improvement which failed to come through as expected was the provision of a manifold between the first and the second stage reactors, connecting the two lines, thereby making it possible for the material to flow from either of the two first stage reactors to either of the two second stage reactors. However, the modified version of Configuration 1 took 3.06 minutes of computer time as compared to 3.96 minutes before the refinements were introduced into the original model.

Analysis of Configuration 1:

Figure 4.6 shows Configuration 1 with the average utilizations of the various facilities and storages mentioned alongside, for Model II, at the end of a simulation run of length 1100 hours of real time.

The facilities at the first stage being unused for a negligibly short time, makes it possible to draw the logical inference that a manifold making a connection as indicated by the dotted line in Figure 4.6, is not likely to improve the performance in any way. Also, the comparatively low utilization of the reactors at the second stage, shows a possible redundancy in the number of these reactors used in this configuration.

It also seems reasonable to provide the means to transfer the material from any of the first stage processors into any of the

TABLE 4.2. Effect of Using Different Random Number Seeds on Production--A Comparison (Configuration 1, Model 2)

	CUMULATIVE PRODUCTION (POUNDS)	
Simulation Run Length (Hours)	Model 2 With R. No. Seeds Set 1	Model 2 With R. No. Seeds Set 2
0	0	0
100	483	497
200	1050	1064
300	1603	1624
400	2156	2184
500	2716	2737
600	3283	3297
700	3843	3864
800	4403	4424
900	4956	4984
1000	5523	5551
1100	6090	6104

second stage processors. The use of one third stage reactor, instead of two, also is justified from the rather low utilization as shown in Figure 4.6.

It, therefore, makes it possible to settle for a rearrangement of the reactors and holding tanks. This rearranged version of the process is shown in Figure 5.1 as CONFIGURATION 2.

CHAPTER 5

CONFIGURATION 2, MODEL 3

5.1. Introduction

In the previous chapter, the procedure adopted to build Model 2 was explained in detail. Also, an analysis of the simulation results obtained from this model brought to light some of the prominent shortcomings of Configuration 1. A series of changes was therefore introduced, the new arrangement of units being referred to as Configuration 2. In this chapter, the development of the computer model associated with this configuration is described. This model is called MODEL 3.

5.2. Description of Configuration 2

The arrangement of the various facilities and storages is pictorially represented in Figure 5.1. In all, there are only thirteen units as compared to seventeen in the previous set-up, not considering the final storage. There are four, three, one and two facilities in the four stages respectively. There is only one holding tank at each of the two levels as against two in the previous models.

The pump sends material into the first holding tank, from which there are four alternative paths leading to the four first

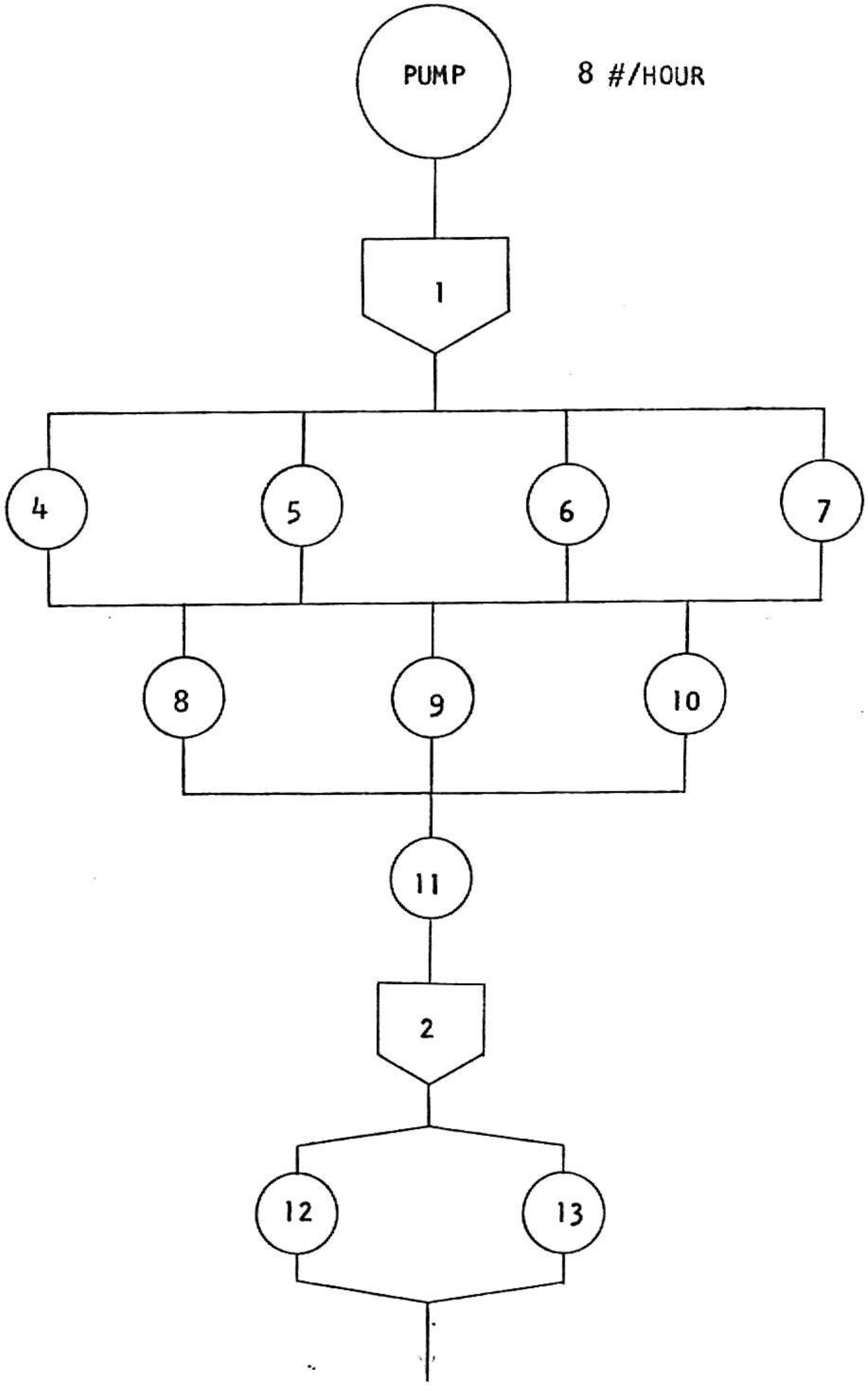


Figure 5.1. Configuration 2, Model 3.
(4-3-1-2 Arrangement)

stage reactor units. Each of these units is capable of discharging its contents into any one of the second stage reactor units. There is one third stage reactor which receives material from any one of the three second stage reactors. After the second level holding tank, there are two lines leading to the fourth stage reactors, which discharge their contents into a final storage, with an infinite capacity.

The capacity of the reactor units remains unchanged at 7 pounds. The two holding tanks have a capacity of 14 pounds each. The pump is considered as a facility and runs only when it is necessary.

5.3. Procedure for building MODEL 3

The generation of the material to be processed, as also the gathering operations at the first holding tank, is in every way similar to the approach adopted in building Model 2. Four transactions are created at the GENERATE block which help start the simulation. These in turn pass into the four first stage reactors, after spending 525 simulation clock units at the pump. The "switching on" of the pump when needed is also similar to the procedure followed in the previous model. Figure 5.2 shows the GPSS/360 block diagram.

5.3.1. First and Second Stage Reactions

The transaction, which represents the material in its various stages of processing, has the option of attempting to enter the

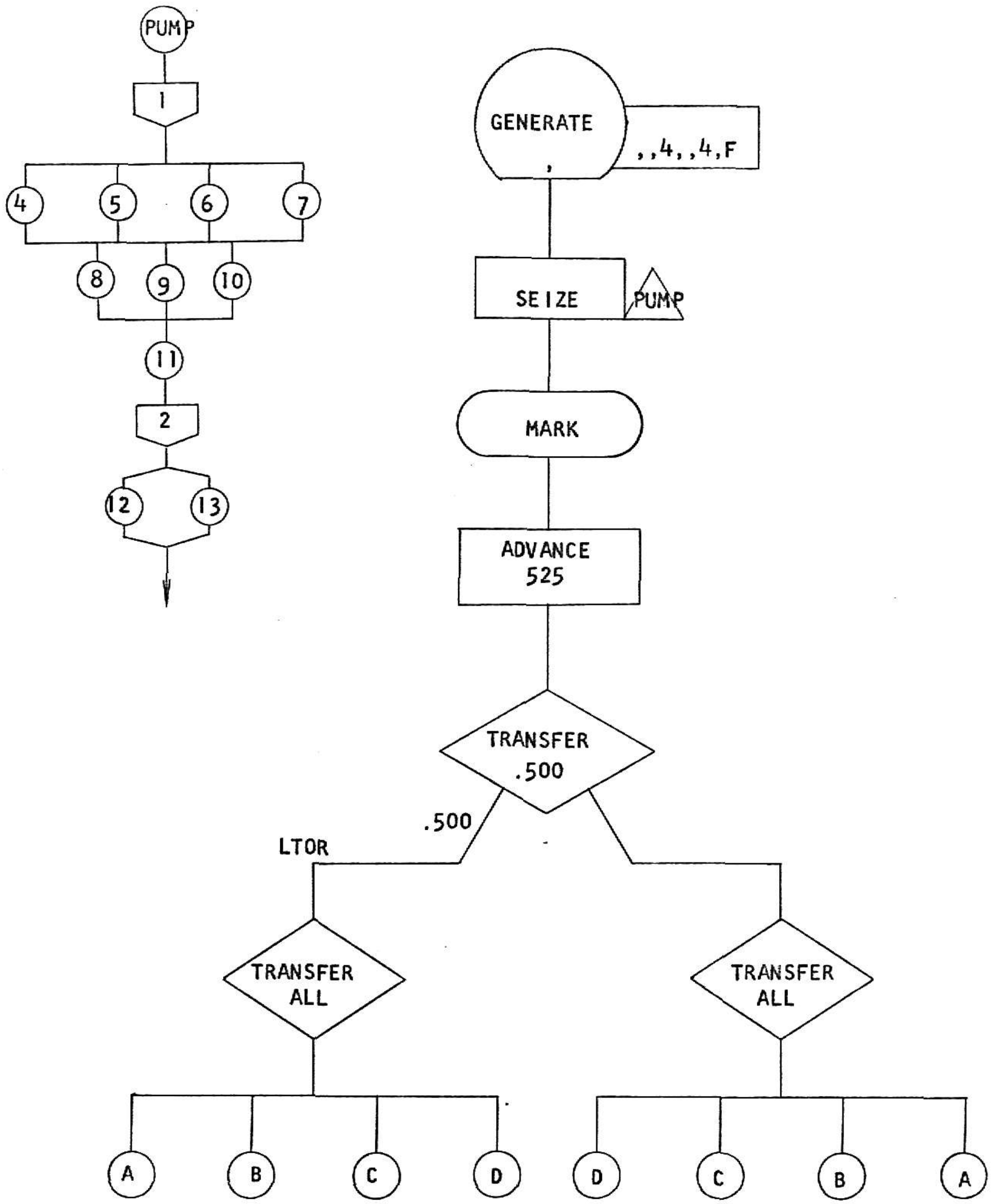


Figure 5.2. Block Diagram for Configuration 2, Model 3.

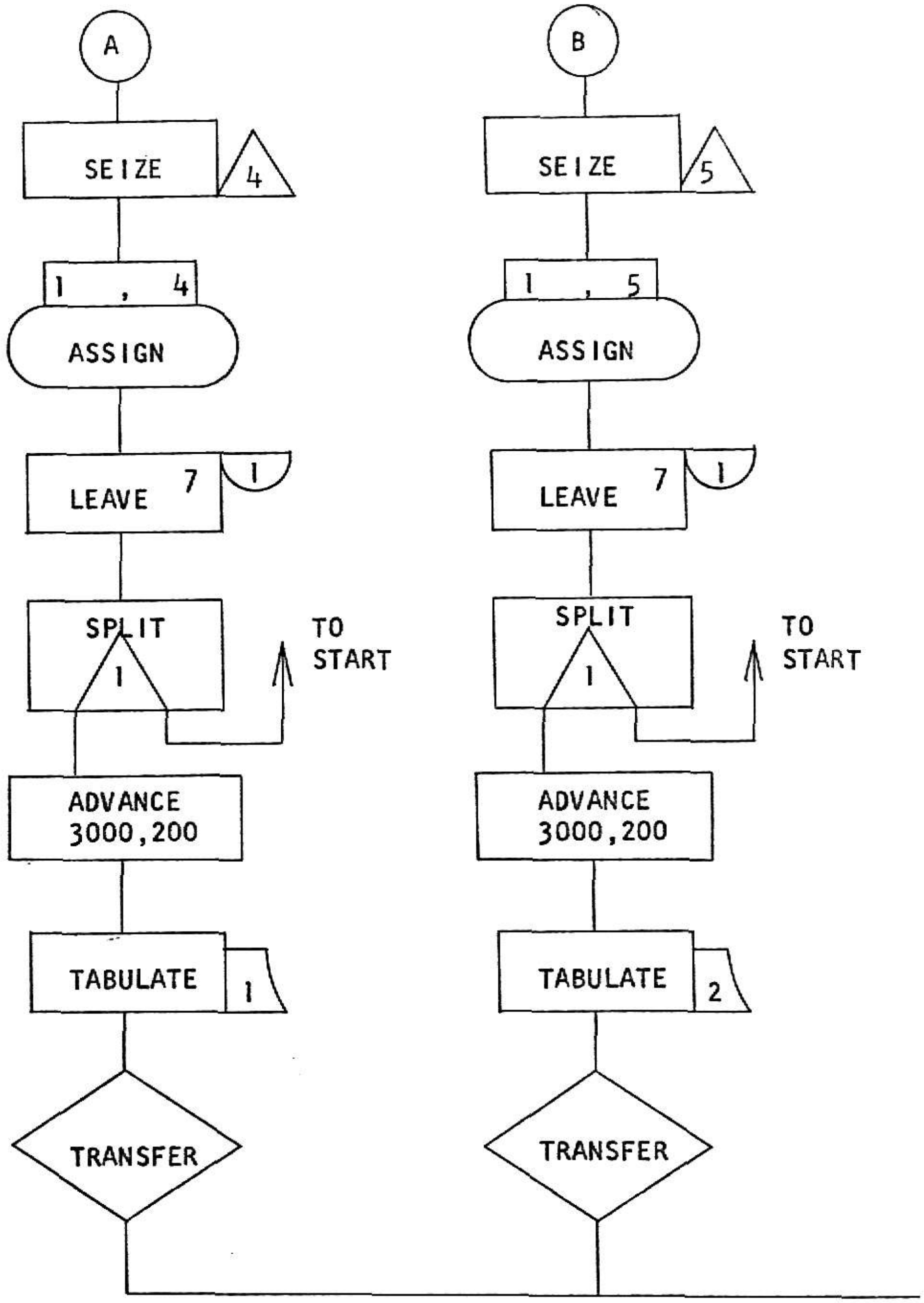
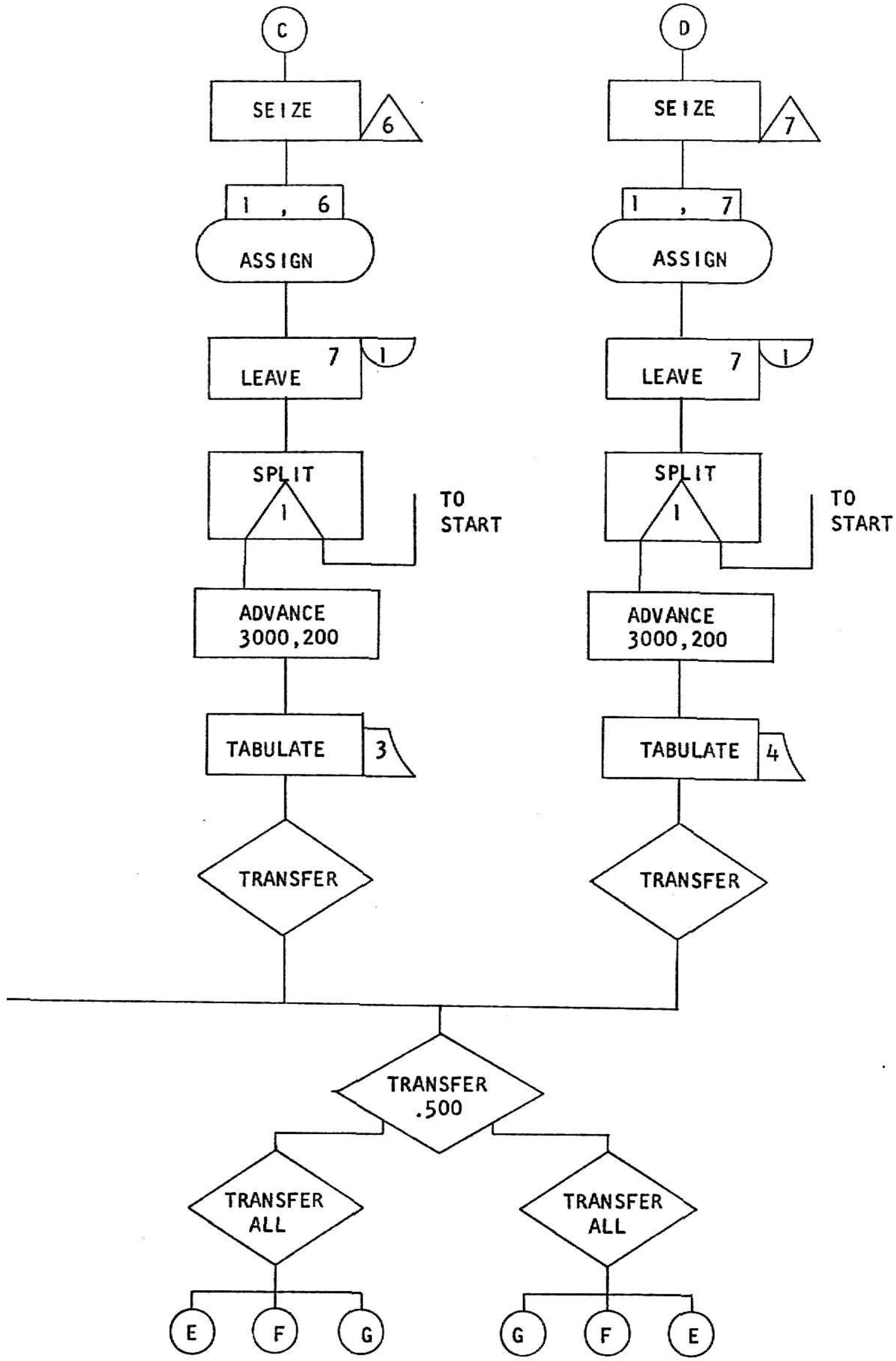


Figure 5.2. (Cont'd).


C
D
SEIZE
6
SEIZE
7
1 , 6
ASSIGN
1 , 7
ASSIGN
LEAVE 7
1
LEAVE 7
1
SPLIT
1
TO START
SPLIT
1
TO START
ADVANCE 3000,200
ADVANCE 3000,200
TABULATE 3
TABULATE 4
TRANSFER
TRANSFER
TRANSFER .500
TRANSFER ALL
TRANSFER ALL
E
F
G
G
F
E

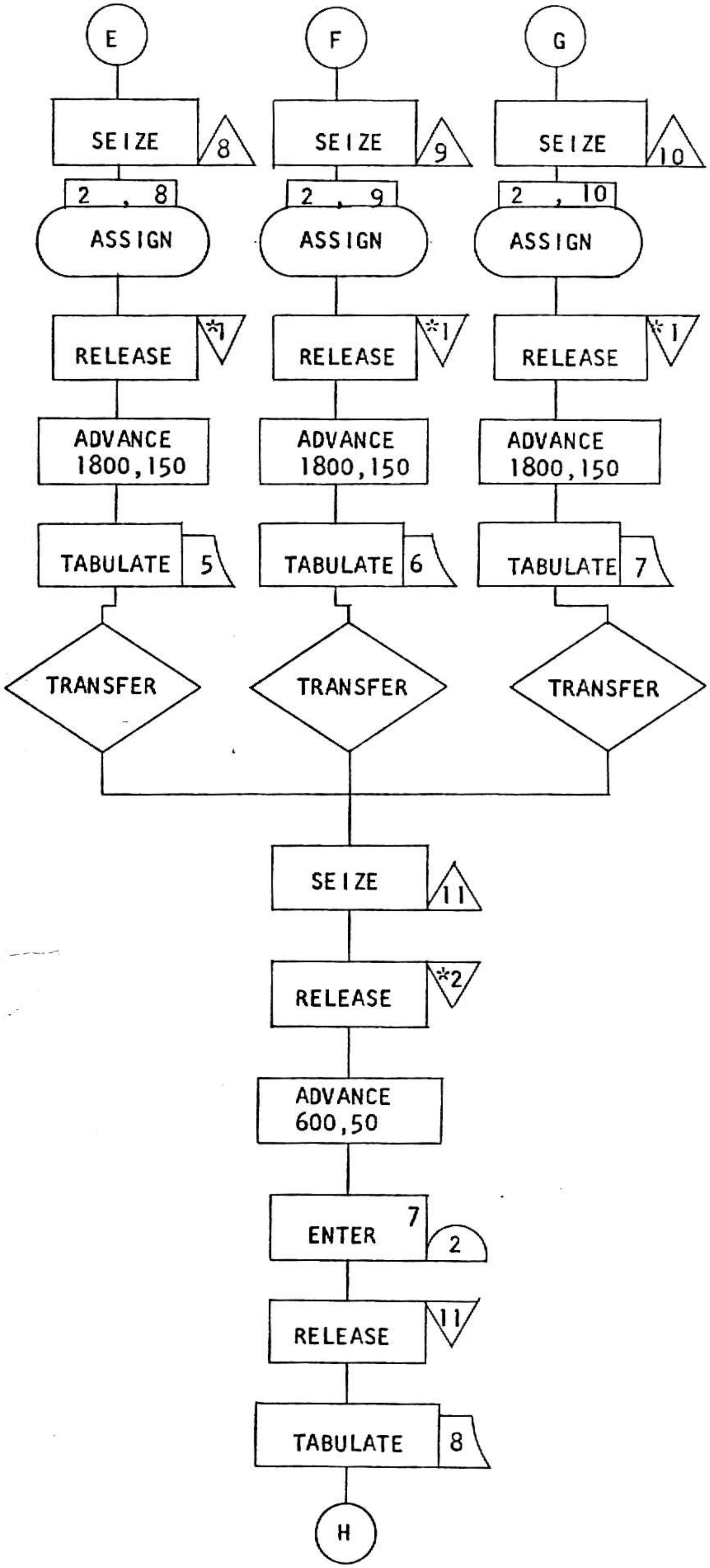


Figure 5.2. (Cont'd).

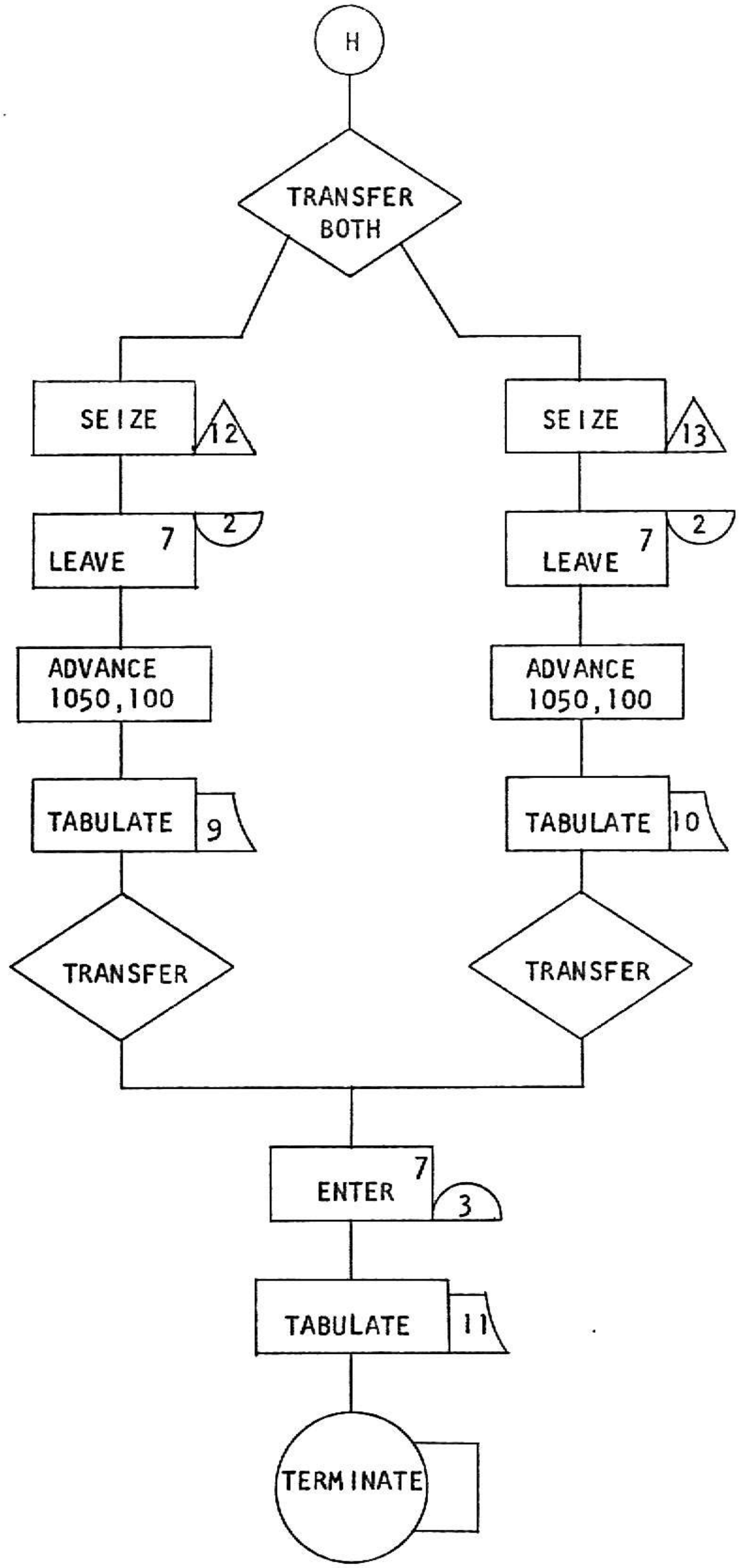


Figure 5.2. (Cont'd).

first stage starting from the left and moving towards the reactors to the right or vice versa. This approach eliminates any bias that might otherwise be present. The units are assumed to be filled instantaneously and the processing is assumed to follow immediately.

The flow from the first stage reactor to the second can be along any of three paths, selected on an equal probability basis. All three reactors at this stage discharge their contents into one third stage reactor.

5.3.2. Third stage reaction and intermediate holding tank at the second level

The third stage reactor receives the material from whichever second stage reactor is ready to discharge its contents and takes 600 simulation clock units to process the material. A variation of 50 simulation clock units is incorporated. The processed material then moves into the second level holding tank. There is not much likelihood of any delay here. A delay can occur only when both the holding tank and the fourth stage reactors are simultaneously occupied. The use of a holding tank with a capacity of 14 pounds and the presence of two fourth stage reactors eliminates any delay.

5.3.3. Fourth Stage Reaction and Final Storage

The flow from the holding tank into the fourth stage reactors is not unbiassed. There is an initial favoring given to the left hand reactor. This, however, was not in any way detrimental to the process and this part of the system took a relatively short time to stabilize and achieve uniform utilization. Immediately after the reaction, the material moves into the final storage, making the reactor available for the following batches awaiting in the holding tank.

The contents of the final storage is the production from the process.

5.4. Data gathered from the simulation

As in the previous models, the information obtained from the simulation consists mainly of frequency distribution of the transaction transit times from the time the material is at the pump to the time the reactions at each successive stage is completed. As part of the standard GPSS/360 output, the storage and facility statistics are printed at the end of each run. The GPSS/360 optional feature of providing simulation data at intermediate stages during the run. The data obtained at the end of every 100 hours of operation are helpful in determining the extent to which the system has attained stabilization.

At the end of the first stage, the transit time distributions in the four lines exhibit a marked similarity, as can be seen from Figure 5.3. This indicates a fair amount of uniformity in the flow of material through these four lines. This can be seen also from an inspection of the mean transit times which are 5976, 5882, 5934 and 5978 simulation clock units or, in real clock time, 9.96, 9.80, 9.89 and 9.96 hours, for a pumping rate of 8 pounds/hour at the end of a simulation run lasting 1100 hours. The cause for this uniform use of the four lines can be attributed to the unbiassed selection of the path of flow from the first holding tank. This is further confirmed at the end of the second stage by such factors as the utilization factor of the three reactors at this stage during the course of the run and the amount of material processed in each of these lines. The left hand, middle and right hand lines processed 1855, 1848 and 1855 pounds of material at the end of 1100 hours of operation. Figure 5.4 shows the distribution of transit times in the three second stage lines.

From the facility statistics, the average time a batch of material spends in a processing unit is seen to be very close to the mean reaction time in that unit, thus indicating an absence of any serious bottleneck in the process. A valuable piece of information that can be gleaned from the storage statistics regarding the second holding tank is that the assumed capacity of 14 pounds is not fully utilized at any time during the 1100 hour run. Also, the seven pound batch of the material stays in the tank for a negligibly short time before moving on to occupy the fourth stage reactor. It seems logical, therefore, to remove from this configuration, the holding tank prior to the fourth stage reactors, because it is a redundant item of equipment. This is justified from another angle also. There cannot be any delay immediately prior to the fourth stage because the arrival rate from the third stage

TABLE 5.1. Comparison of Unit Utilizations in Models 2 and 3 at the End of 1100 Hours (Pumping rate: 8 #/hour)

Unit	MODEL 2	MODEL 3
Pump	.700	.694
Stage 1	1.000	1.000
Stage 2	.618	.854
Stage 3	.400	.794
Stage 4	.702	.695

is one batch per hour on the average, and one or the other of the two subsequent reactor units is always available. (Processing time 1.75 hours.)

Table 5.1 provides a comparison of the average utilization factors of the units in the four stages in Models 2 and 3. Since the number of units per stage varies in these two models, only the average utilization of each stage has been used as a means of comparison. There is a very distinct improvement in the extent to which the reactors in Configuration 2 have been utilized.

Simulation runs of duration 1100 hours were made at different pumping rates, varying from 4 pounds/hour upwards. Figure 5.5 shows the effect of varying the pumping rate on the production rate and the cumulative production at the end of 1100 hours of operation. Figures 5.6 and 5.7 show the distribution of the final transit times (from the time the material is at the pump to the time it emerges as the finished product at the end of the fourth stage) at these pumping rates.

For every frequency distribution table, the GPSS/360 output editor also provides the mean transit time and the standard deviation from this mean time. Figure 5.8 is a plot of the mean final transit time, which is the average production time per batch of 7 pounds of finished product, against pumping rate. There is a steady fall in the magnitude of these means till a rate of 5.5 pounds/hour is reached. Then there is a very sudden increase from a 5.5 pounds/hour rate to that at 6 pounds/hour. From this pumping

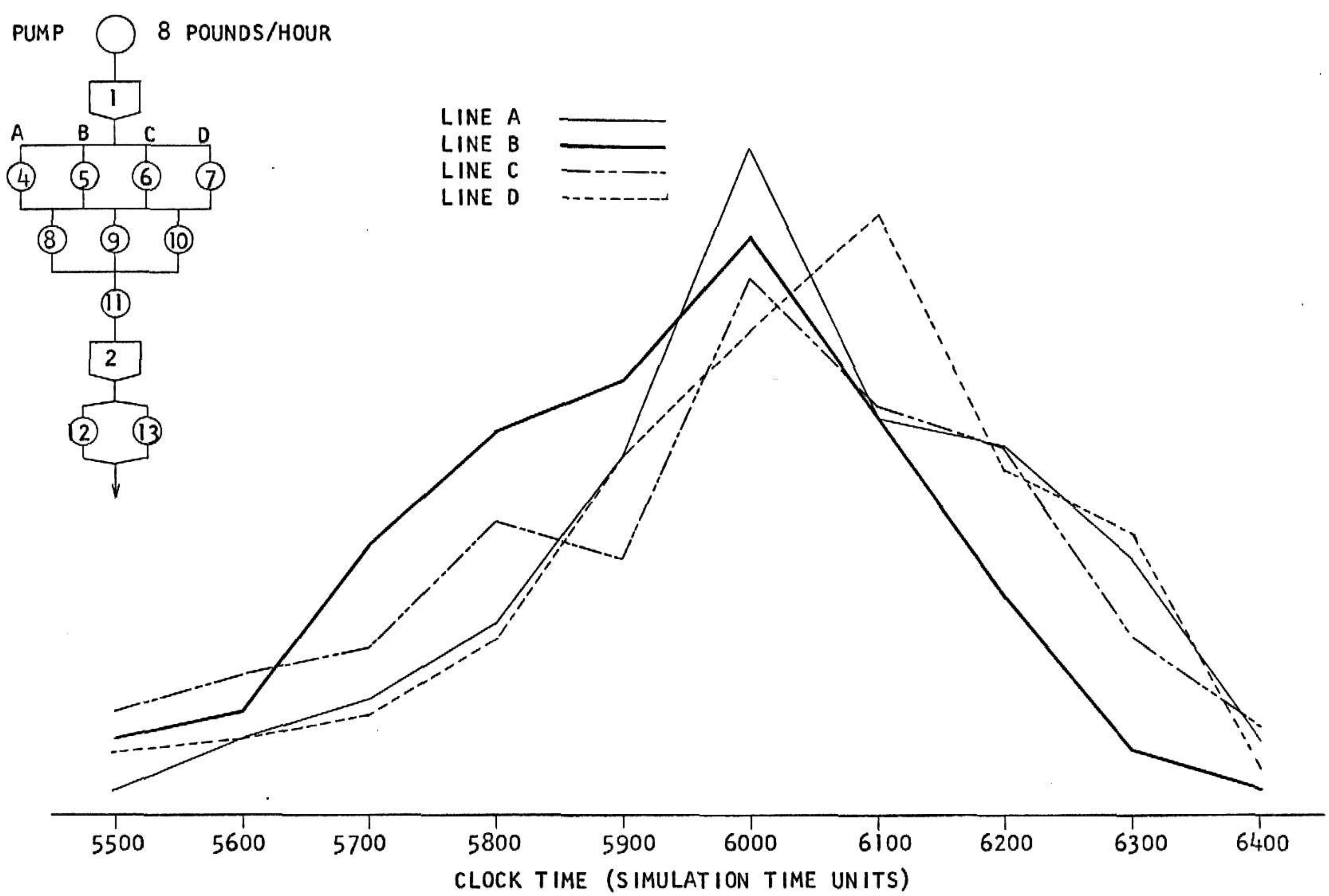


Figure 5.3. Distribution of Transit Times Till End of First Stage in the 4 Lines in Configuration 2, Model 3.

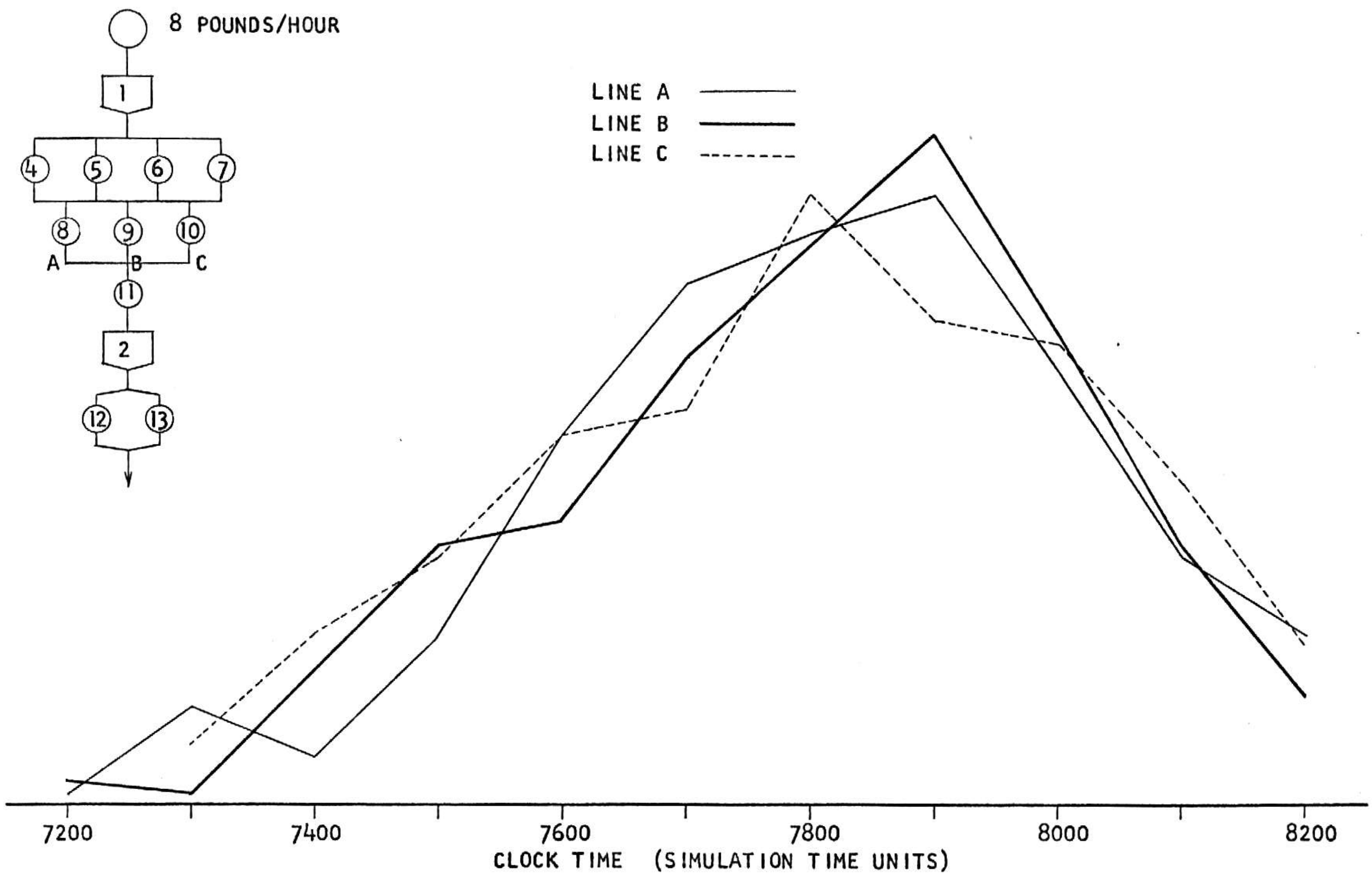


Figure 5.4. Distribution of Transit Times Till the End of Second Stage for Configuration 2, Model 3.

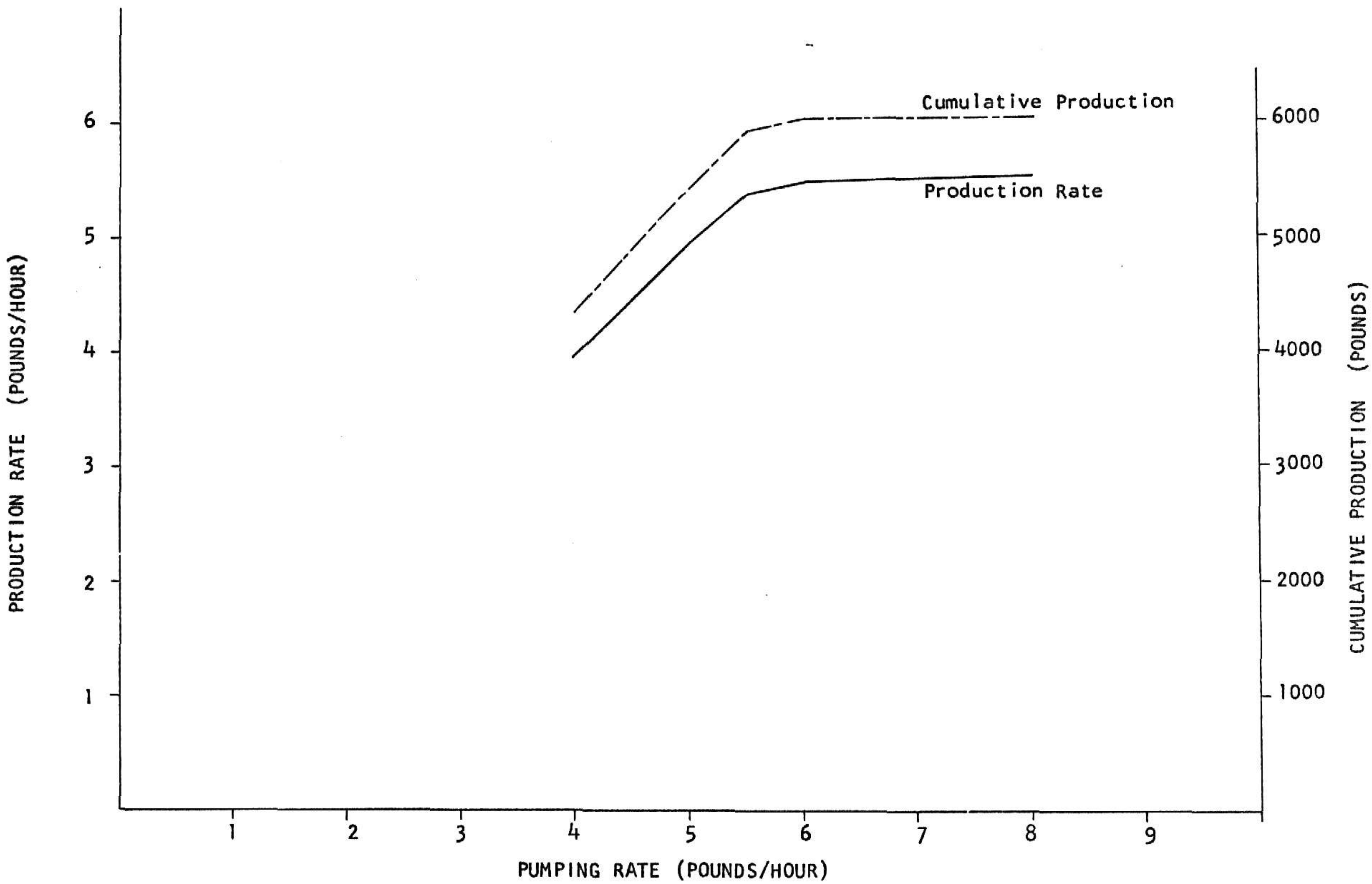


Figure 5.5. Effect of Varying Pumping Rate on Cumulative Production and Production Rate for Configuration 2, Model 3.

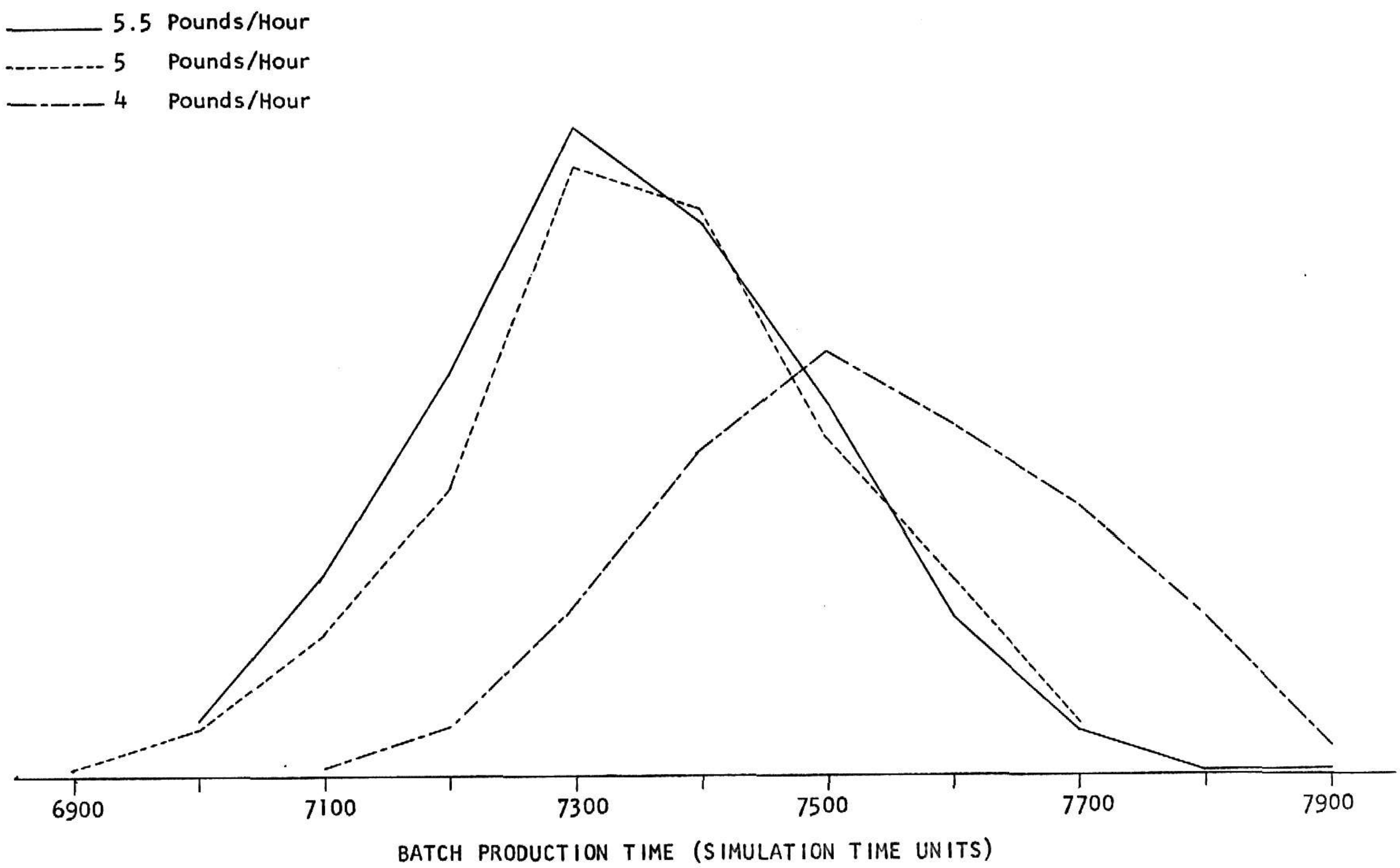


Figure 5.6. Distribution of Batch Production Time at Different Pumping Rates for Configuration 2, Model 3.

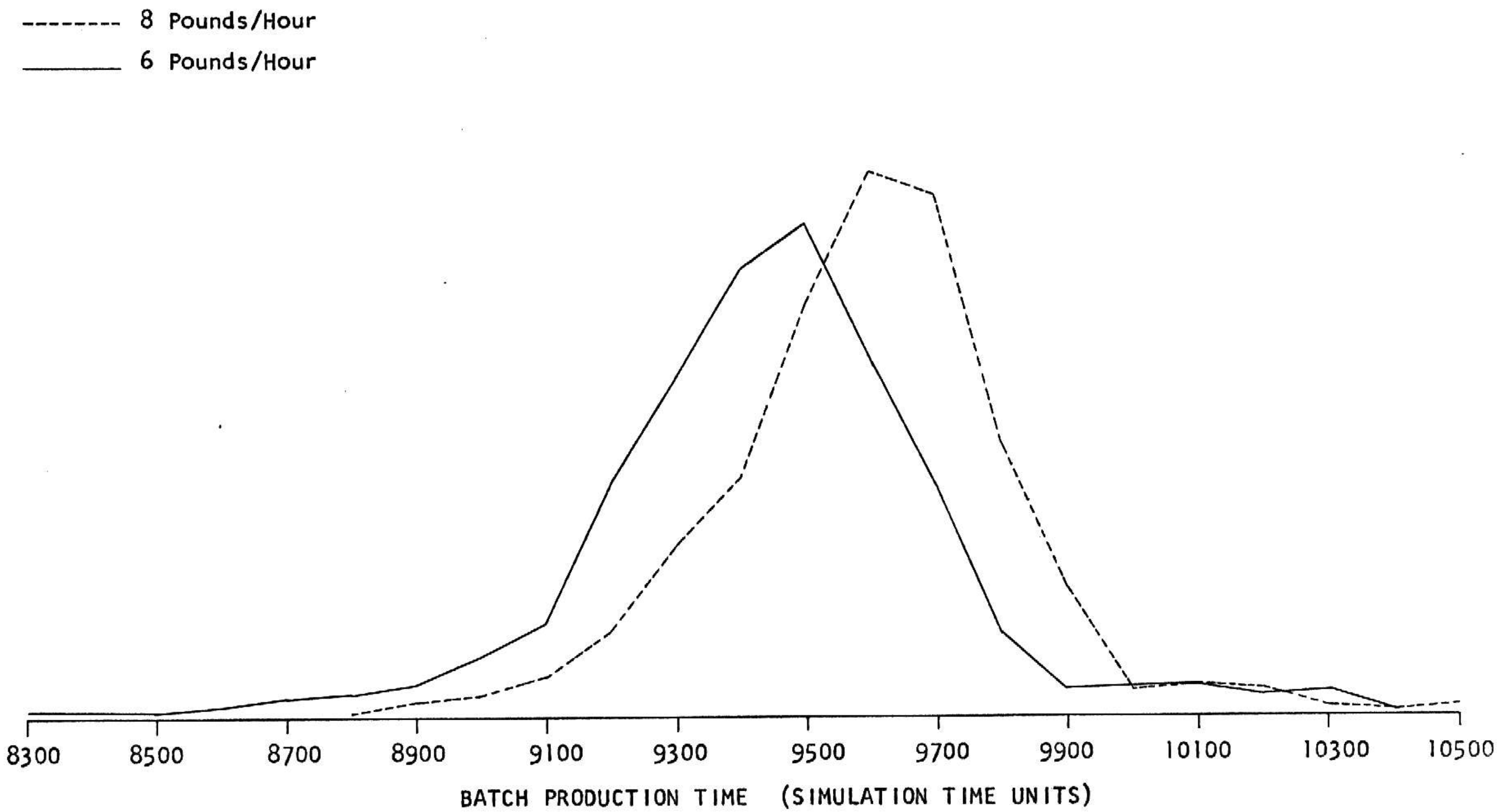


Figure 5.7. Distribution of Batch Production Time at Different Pumping Rates for Configuration 2, Model 3.

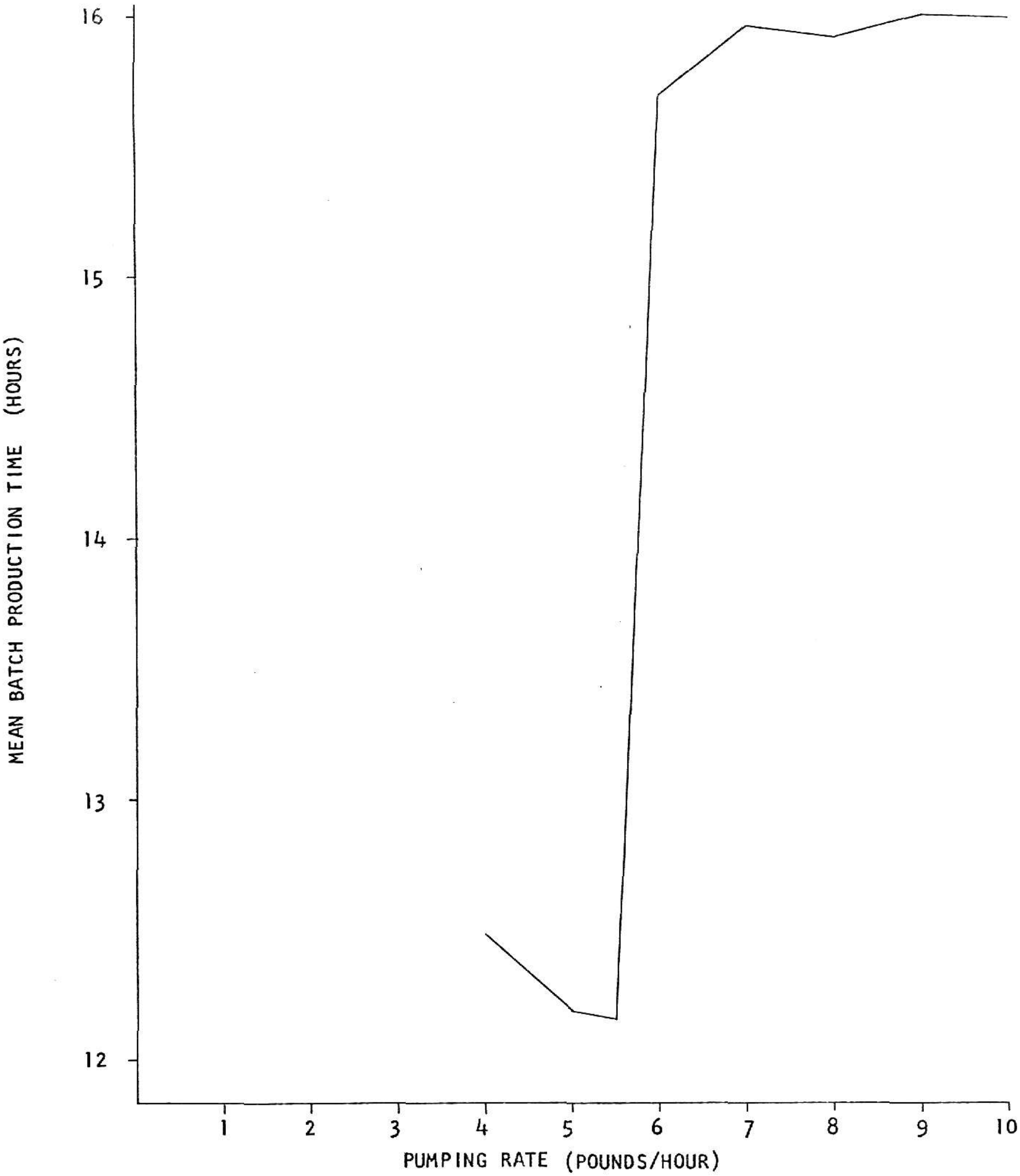


Figure 5.8. Effect of Varying the Pumping Rate on the Mean Batch Production Time for Configuration 2, Model 3.

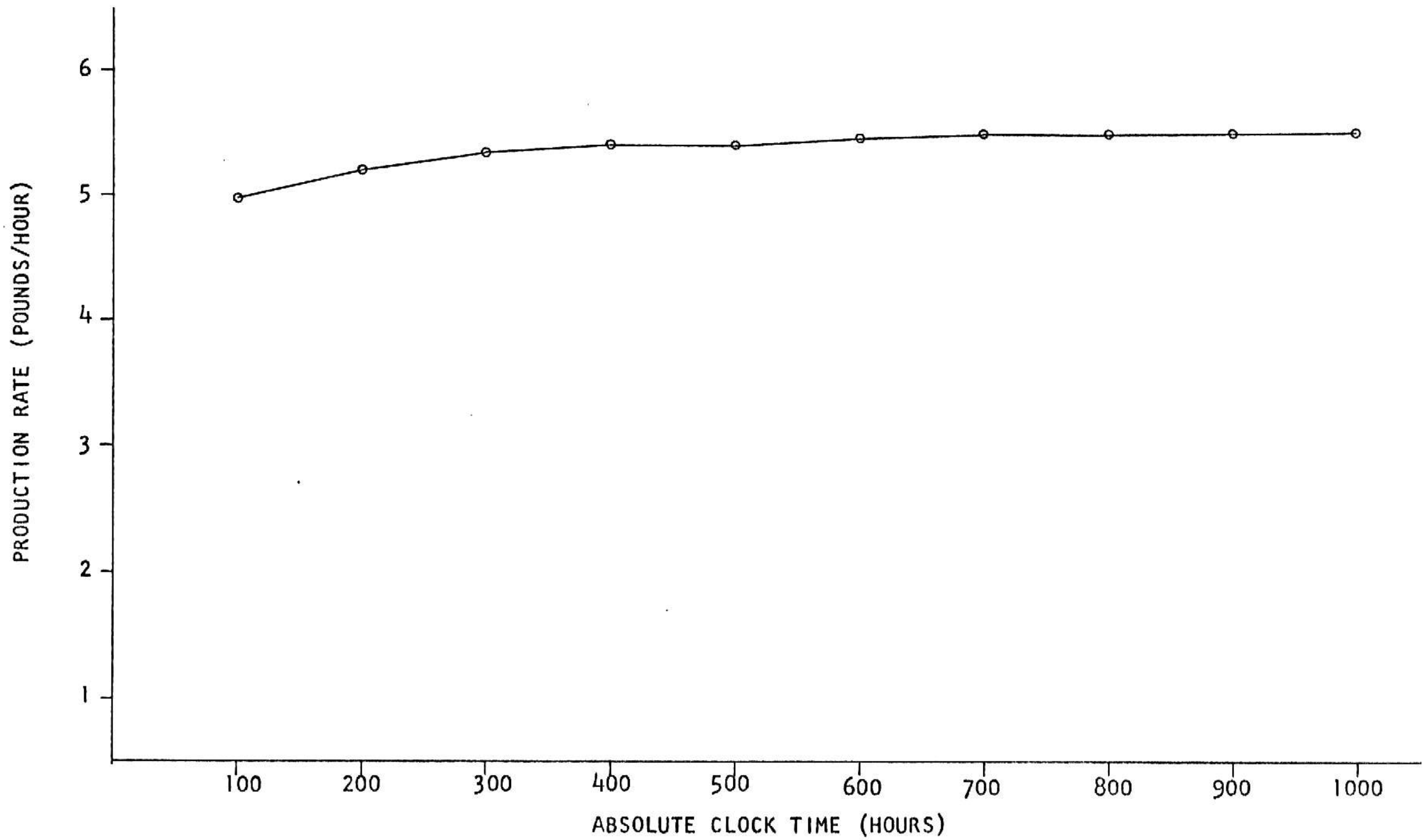


Figure 5.9. Production Rate for Configuration 2, Model 3 at a Pumping Rate of 8 Pounds/Hour.

rate onwards, the curve levels off and indicates a tendency for the system to stabilize. For example, with a relatively low pumping rate of 4 pounds/hour, a considerable amount of time is spent in filling the reactor vessels at the first stage, thereby creating an unnecessary delay. This delay adversely affects the batch production time. Understandably, it gets reduced as the pumping rate is gradually increased. The system is in a transient state between the rates of 5.5 and 6 pounds/hour before stabilizing at higher pumping rates.

This model exhibits more steadiness than either of the two previous models. This can be seen from the production rate and the production per 100 hour interval which attain fairly constant values within 200 hours of start up (see Figure 5.9). Also, the production rate is markedly higher than that in the previous models. During runs of equal length, the second configuration produced as much as 500 pounds more than the first configuration. Another factor of significance is that this increase was achieved while using only 13 units, not counting the final storage, as against 17 units in the first two models.

CHAPTER 6

CONFIGURATION 3, MODEL 4

6.1. Introduction

A model, which is free from most of the defects and shortcomings inherent in Models 1 and 2, has been developed and analyzed. This model with a different arrangement of the processing units, manifolds and holding tanks has been called Model 3, Configuration 2. This arrangement has a total of twelve units, after discarding the second holding tank between the third and the fourth stage reactors. As before, the infinite capacity final storage has not been considered as a unit on a par with the others. The use of this configuration, which employs less of equipment and yet has a more uniform unit utilization factor, is certainly preferable to either of the earlier models.

Once the system had been made free of the undesirable characteristics and modelling crudities, some justifiable changes were incorporated in an effort to improve performance. These changes are in the nature of an additional unit at one or more stages in the process. The first change attempted was the addition of a fifth reactor at the first stage. Here it appeared logical to expect a reduction in the average utilization of the first stage reactors and an increase in the average utilization of the second

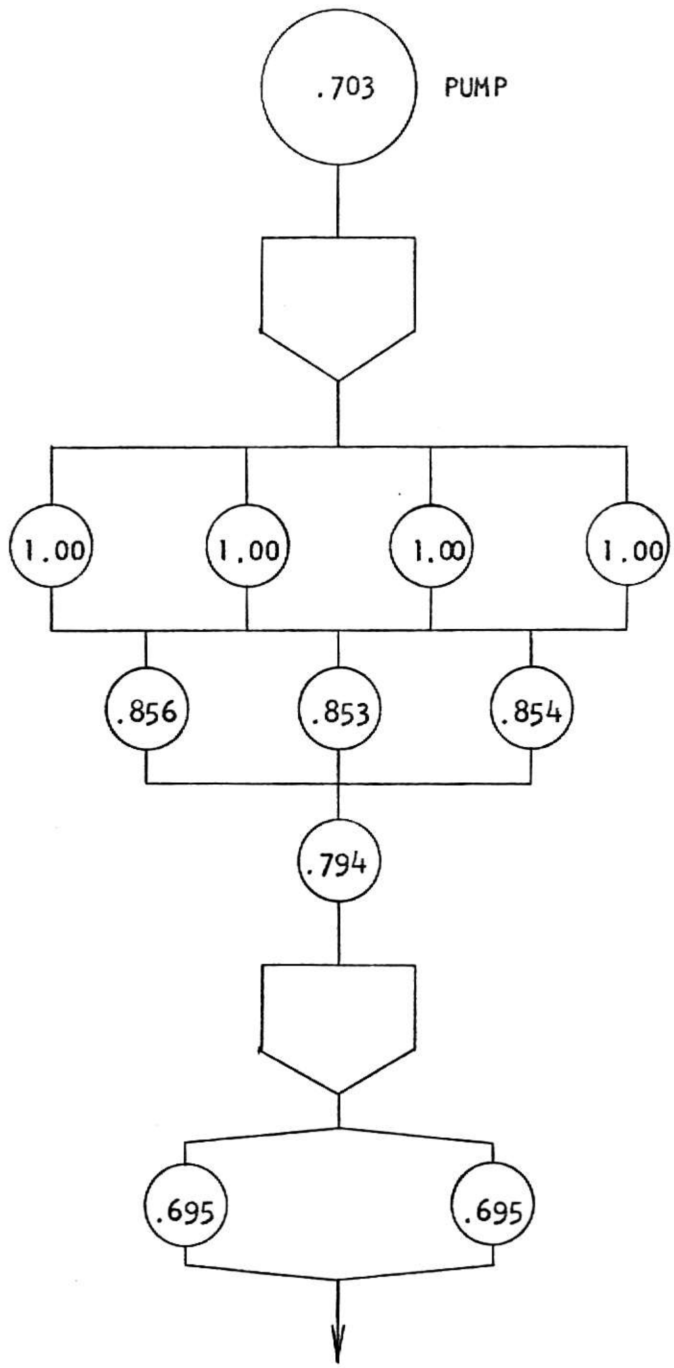


Figure 6.1. Configuration 2, Model 3 (4-3-1-2 Arrangement), Showing Unit Utilizations.

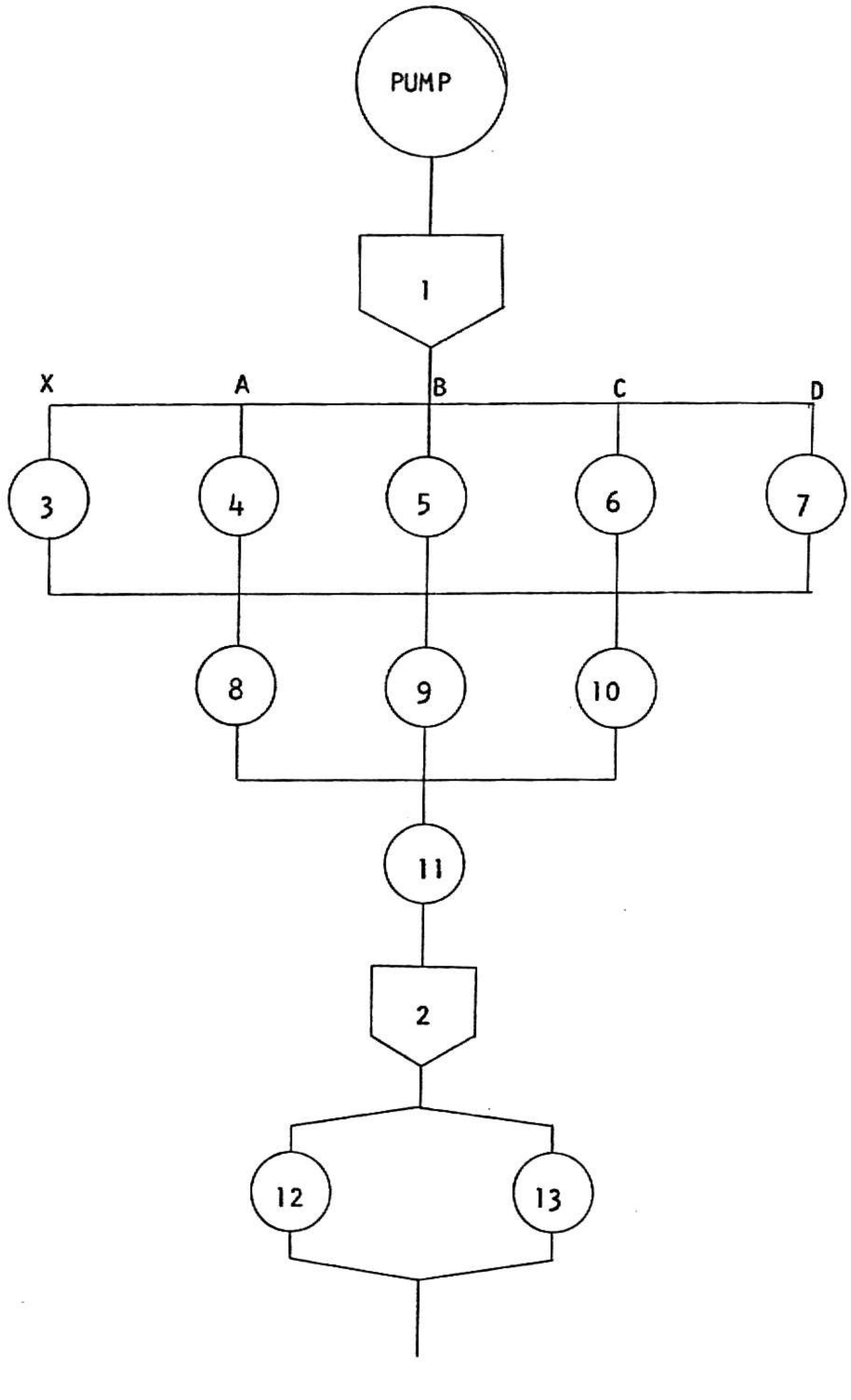


Figure 6.2. Equipment Arrangement for
Configuration 3, Model 4 (5-3-1-2 Arrangement)

stage reactors. The difference between the first and second stage utilization is not unnoticeable in Model 3. Figure 6.1 shows Configuration 2, Model 3 along with the individual unit utilizations. It can be seen that there is still room for some improvement as far as unit utilizations are concerned.

6.2. Description of Model 4, Configuration 3

The addition of a reactor at the first stage alters the configuration of equipment. This arrangement of units has been called Configuration 3, Model 4. Figure 6.2 shows the arrangement of units in this configuration. As can be seen, the only difference between this model and the previous model is the fifth unit at the first stage.

The pump feeds a single holding tank at the rate of 8 pounds/hour. The material has a choice of five paths to reach the first stage reactors. Each path has an equal probability of being chosen. The pump is "switched on" as before whenever the material leaves the holding tank to occupy one of the five reactors at the first stage.

Subsequent flow from the first stage can be along any one of three lines, each having an equal probability of being used by the processed material from any one of the first stage reactors. On completion of processing, the material flows into the only unit at the third stage, with the processing time being uniformly distributed in the range 1 hour $\pm$ 5 minutes.

The fourth stage consists of two parallel lines. Priority has,

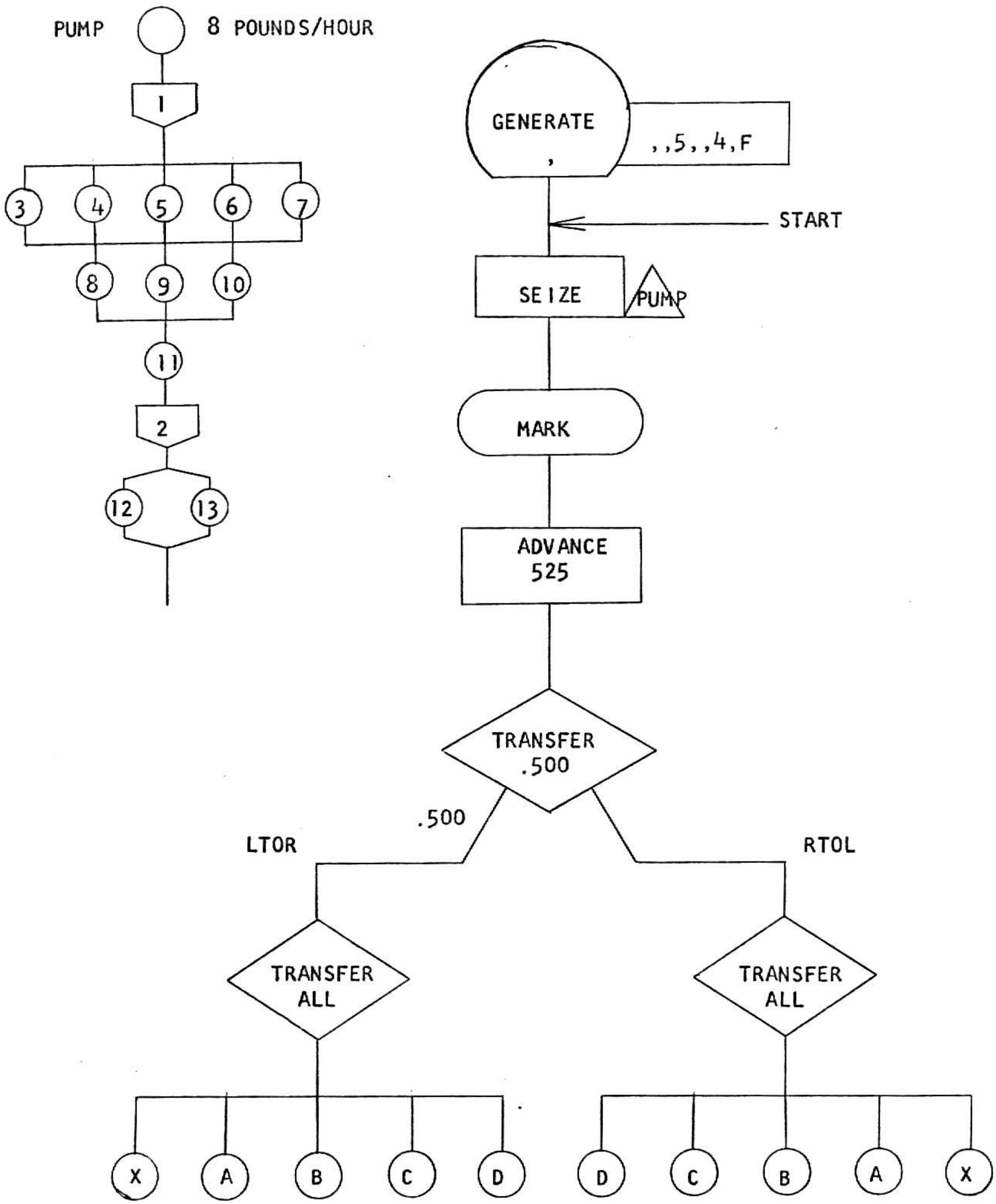


Figure 6.3. (Cont'd). GPSS/360 Block Diagram
for Configuration 3, Model 4.

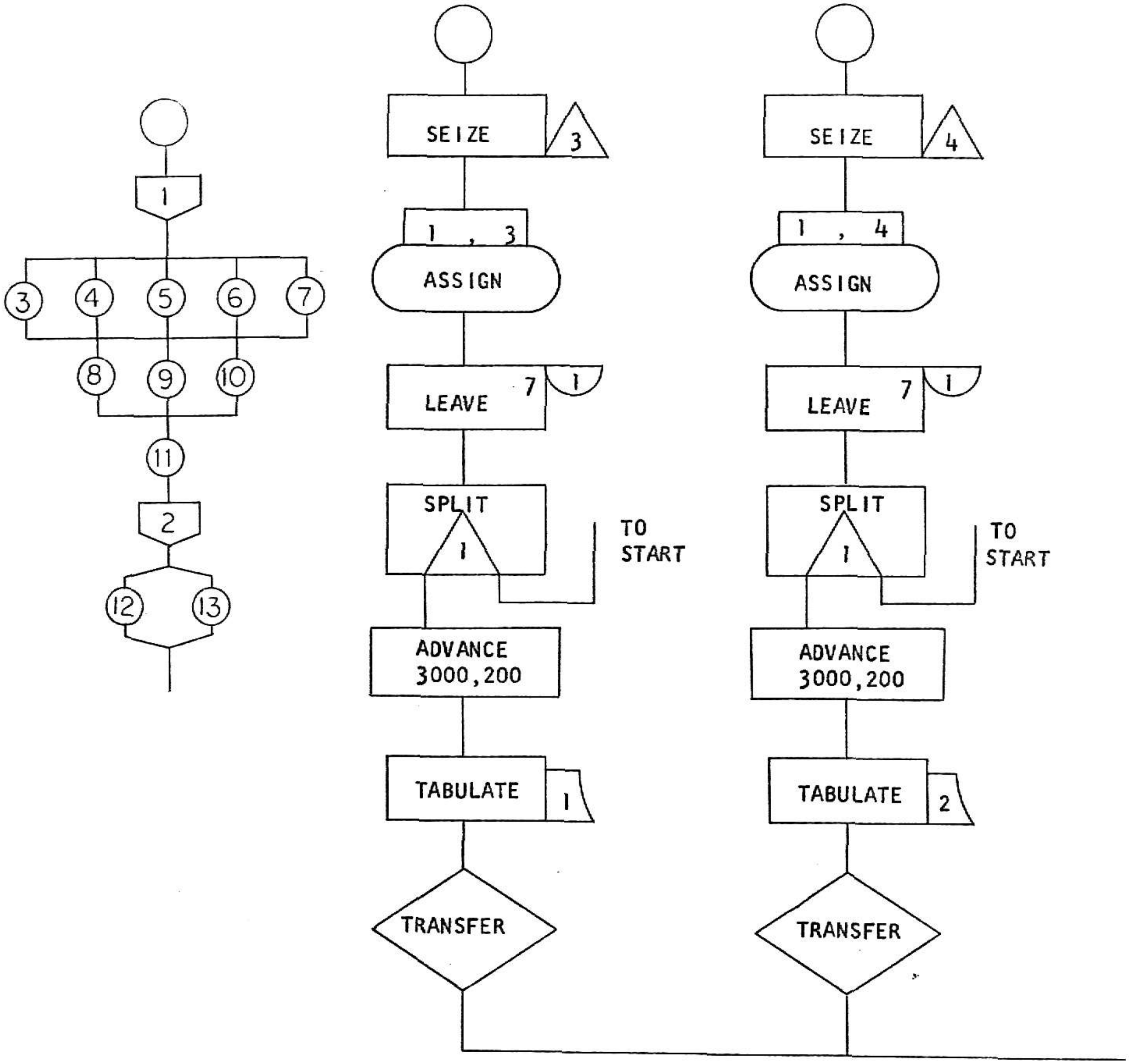
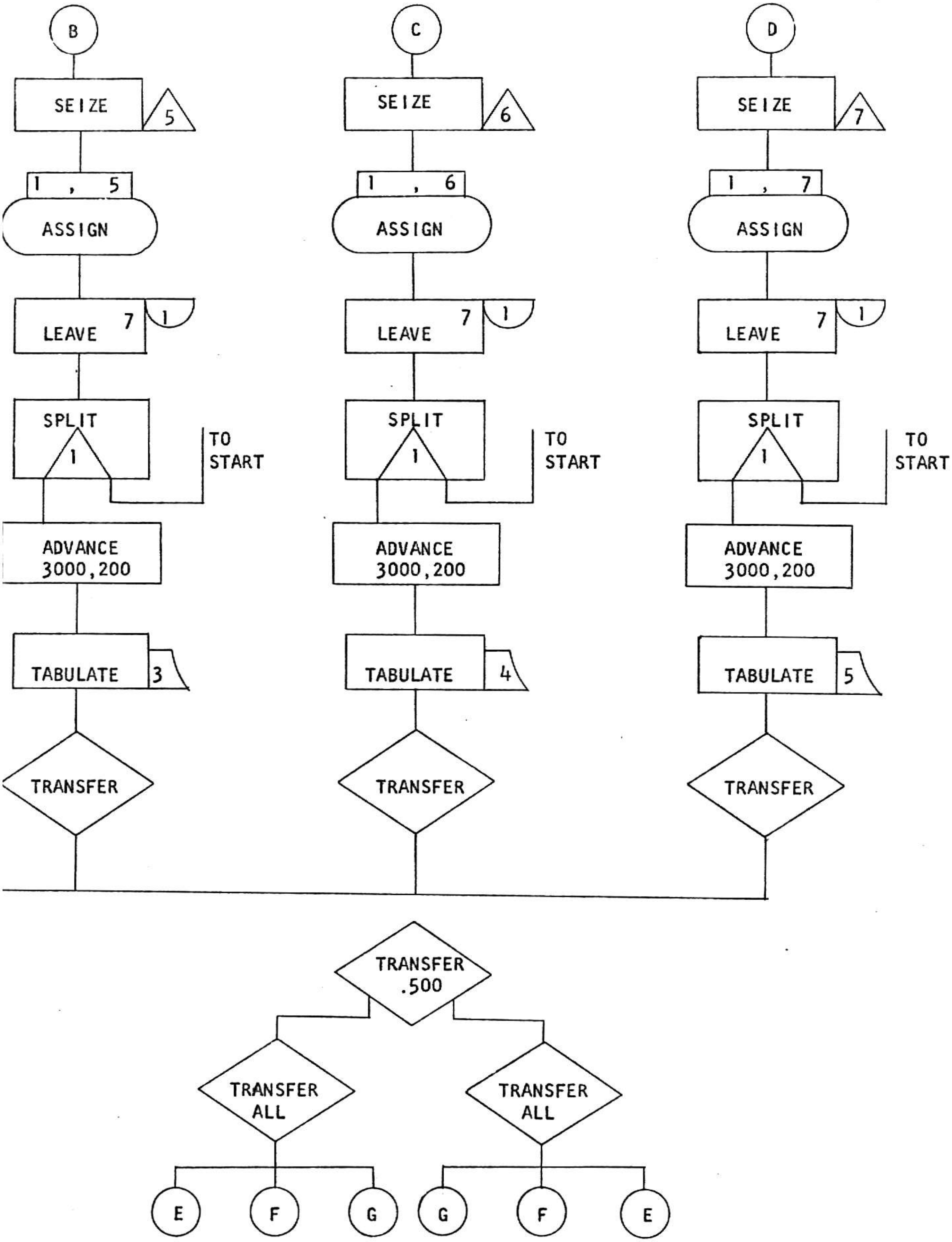


Figure 6.3. (Cont'd)
The rest of the Block Diagram is identical to that of Configuration 2, Model 3, shown in Figure 5.2.


B
C
D
SEIZE
5
SEIZE
6
SEIZE
7
1 , 5
ASSIGN
1 , 6
ASSIGN
1 , 7
ASSIGN
LEAVE 7
1
LEAVE 7
1
LEAVE 7
1
SPLIT
1
TO START
SPLIT
1
TO START
SPLIT
1
TO START
ADVANCE 3000,200
ADVANCE 3000,200
ADVANCE 3000,200
TABULATE
3
TABULATE
4
TABULATE
5
TRANSFER
TRANSFER
TRANSFER
TRANSFER .500
TRANSFER ALL
TRANSFER ALL
E
F
G
G
F
E

as before, been given in favor of the reactor on the left hand line. At the end of the fourth stage, the material emerges as the finished product and immediately passes into the final storage. There is no delay here because the capacity of this storage has been assumed to be infinite. The contents of the final storage gives the cumulative production.

6.3. Block diagram

The block diagram for the GPSS/360 model for this configuration is given in Figure 6.3. It depicts the flow of material till the end of the first stage only. Subsequent flow is similar to that in Configuration 2, Model 3, and the rest of the block diagram is, therefore, identical to that shown in Figure 5.2.

As in the case of the previous model, the GPSS/360 feature, MACROs were made use of in the flow of material wherever alternative paths were available. For the sake of convenience the same names were given the MACROs as were given in the previous model. These were, in turn, MACRO XXXX for the first stage, MACRO YYYY for the second stage and MACRO FOUR for the fourth stage.

6.4. Data gathered from the simulation

Consistent with the practice thus far, data gathered during the course of the simulation consist.of frequency distributions of the transaction transit times from generation to the end of each of the four reaction stages. To obtain information on the performance of the model as a whole and a comparison on how the different parts of the configuration are functioning, frequency distributions have been tabulated in each line at each stage. Storage and facility statistics are printed out as part of the standard GPSS/360 output. From these statistics, it is possible to determine whether the material is held up unnecessarily at any point in the process and whether the storage and holding tank requirements are adequately met.

Simulation runs of duration 1100 hours were made, the relative clock being RESET after the first 100 hours of operation. The first of these runs was made with a pumping rate of 8 pounds/hour, the simulation data being obtained at the end of every 100 hours. Runs of equal duration (1100 hours) were then made at different pumping rates, from 4 pounds/hour to 10 pounds/hour.

6.4.1. Transit time distributions

Whenever a TABULATE block is encountered in a program, GPSS/360 tabulates the entity specified along with the upper limits of the frequency classes and the corresponding frequencies. The mean argument for every distribution tabulated is also printed at the head of every tabulation. The entity being studied for its distribution is the (transaction) transit time from the time the material is at the pump to the time the processing is completed at each stage.

Figures 6.4, 6.5 and 6.6 show the transit time distributions on completion of processing at the first, second and fourth stages at a pumping rate of 8 pounds/hour. The figures correspond to the conditions at the end of a simulation run of 1100 hours. The transit times in the five lines at the first stage (Figure 6.4) have noticeably similar distributions. Their mean values in these lines are 5520, 5526, 5516, 5522 and 5519, with an average of 5520.6. In Model 3, the corresponding average transit time till the end of the first stage was 5942. In real clock time, these two transit times are 9.20 and 9.90 hours at a pumping rate of 8 pounds/hour.

The amount of material passing through each of the three lines in the second stage is 2233 pounds at the end of a simulation run lasting 1100 hours. This similarity of performance of these reactors and the average utilization factors achieved indicate a stable model behavior and the effectiveness of the unbiassed material transfer from stage to stage.

From the facility statistics at the end of the 1100 hour simulation, the average time a batch of material spends in a processing unit is seen to be very close to the mean reaction time in that unit. This indicates an absence of any major bottleneck at any stage in the process. From the storage statistics corresponding to the final storage, the cumulative production is obtained. Figure 6.6 shows the rate of production at the end of every 100 hours, over the 1100 hour simulation, for a pumping rate of 8 pounds/hour.

Table 6.1 provides a comparison of the average utilizations of the pump and the reactors at each of the four reaction stages in Models 2, 3 and 4. It can be seen that the inclusion of the fifth

TABLE 6.1. Comparison of Average Utilization in Models 2, 3 & 4 (Configurations 1, 2 & 3)

	Average Unit Utilization at the End of 1100 Hours Run		
Unit	Model 2	Model 3	Model 4
Pump	0.700	0.694	0.834
Stage 1	1.000	1.000	1.000
Stage 2	0.618	0.854	0.991
Stage 3	0.400	0.794	0.954
Stage 4	0.702	0.695	0.836

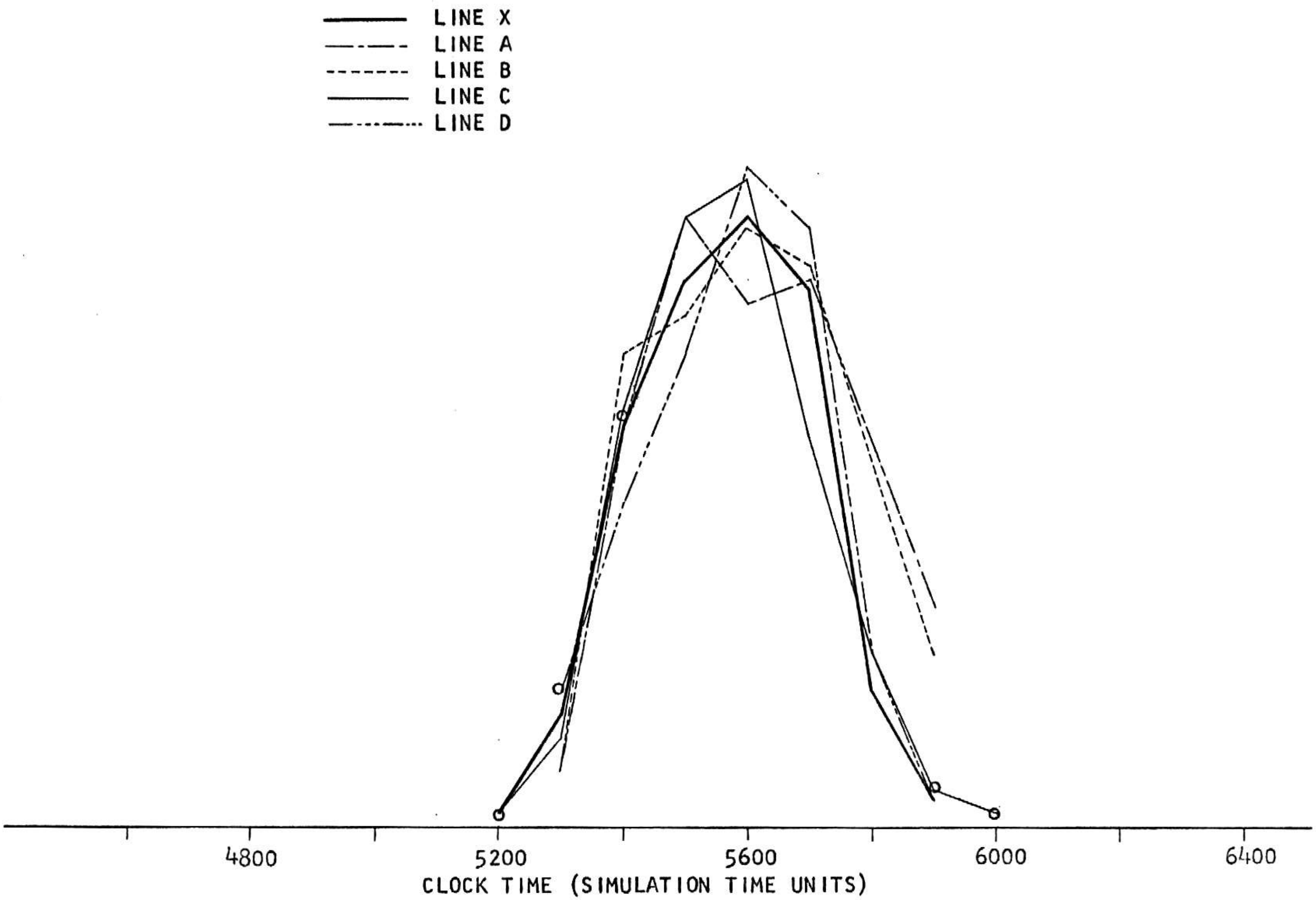


Figure 6.4. Distribution of Transit Time in the Five Lines at the End of the First Stage in Configuration 3, Model 4.

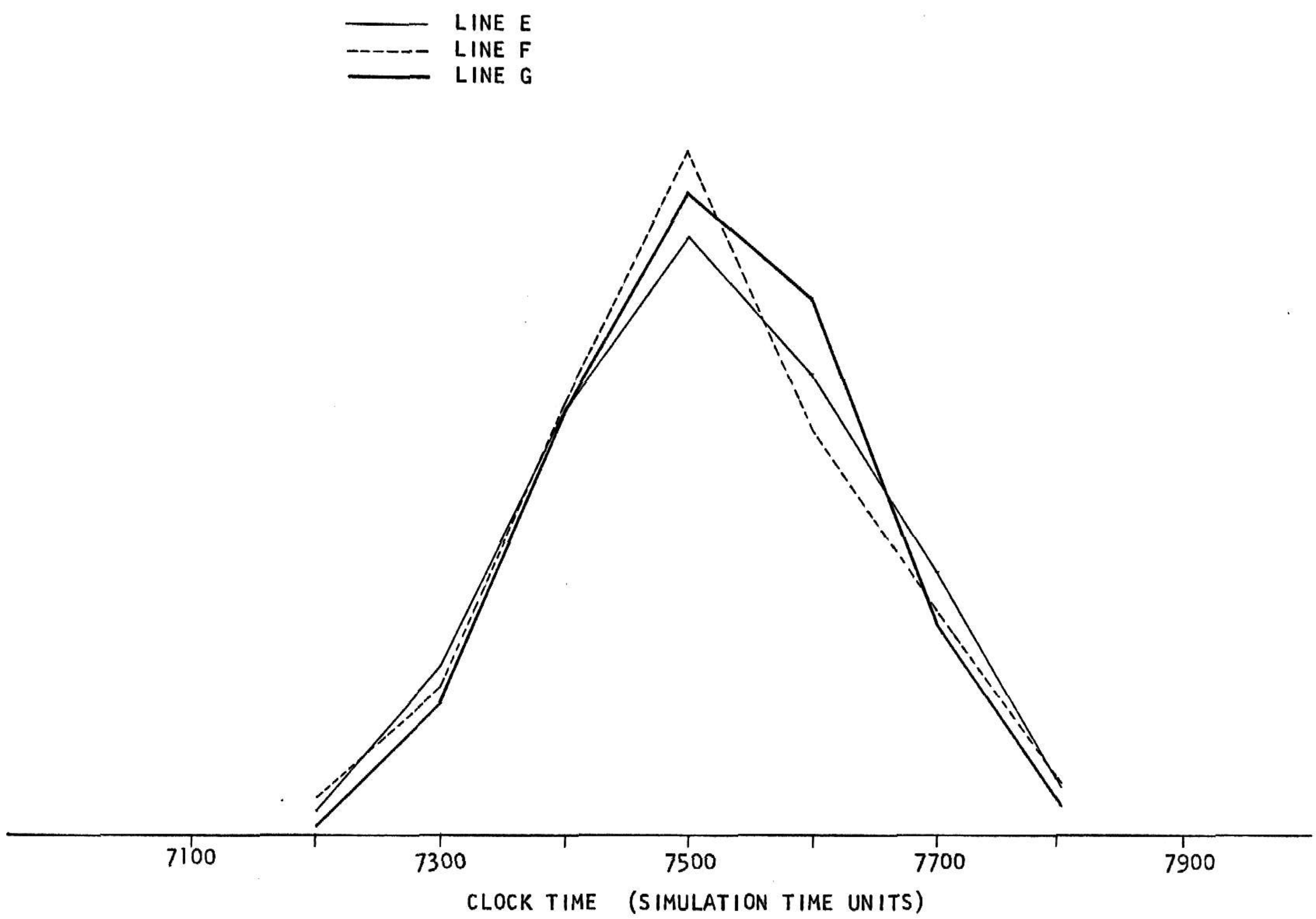


Figure 6.5. Distribution of Transit Time in the Three Lines at the End of the Second Stage in Configuration 3, Model 4.

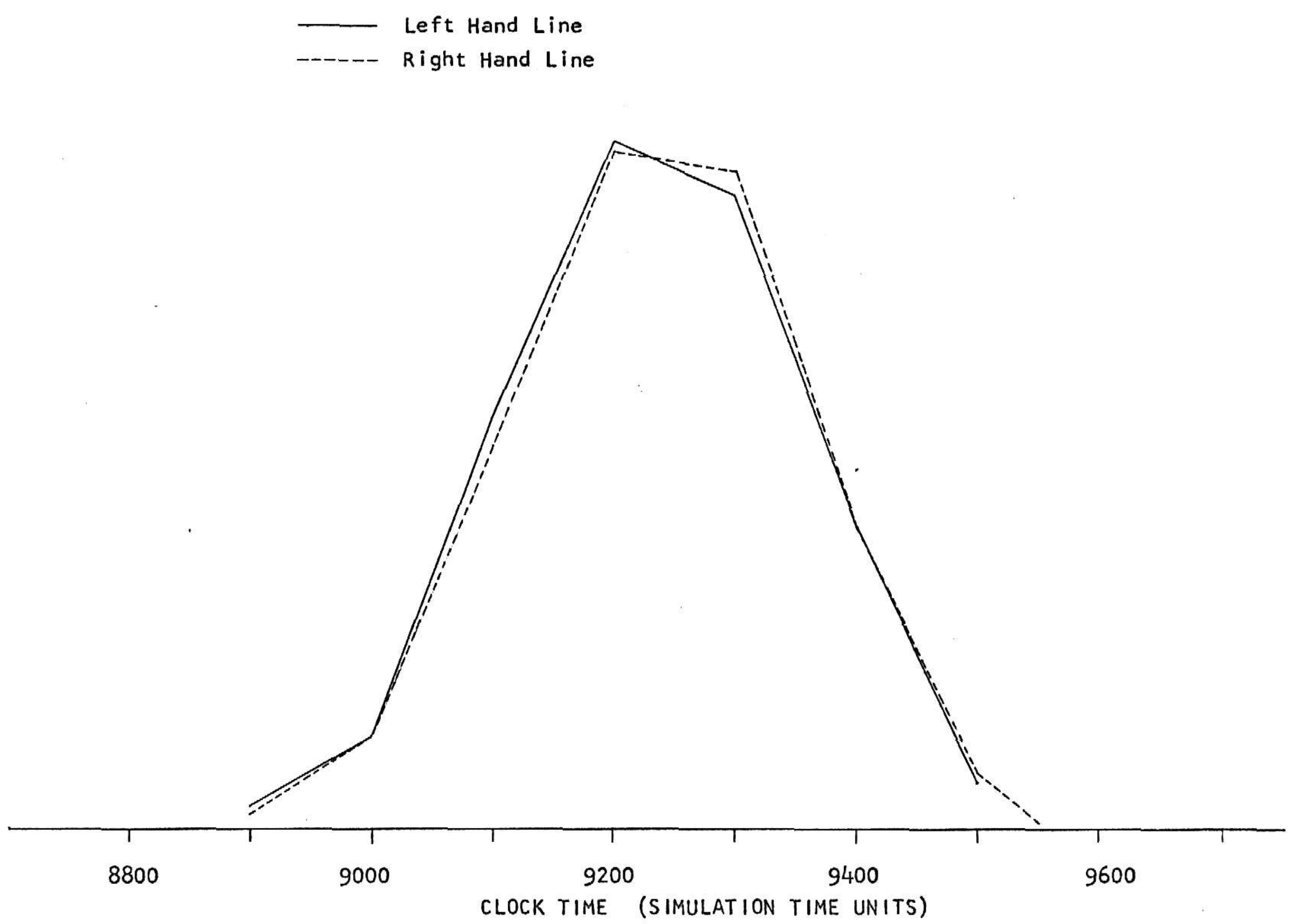


Figure 6.6. Distribution of Transit Times at the End of the Fourth Stage Reactors in Configuration 3, *Model 4*.

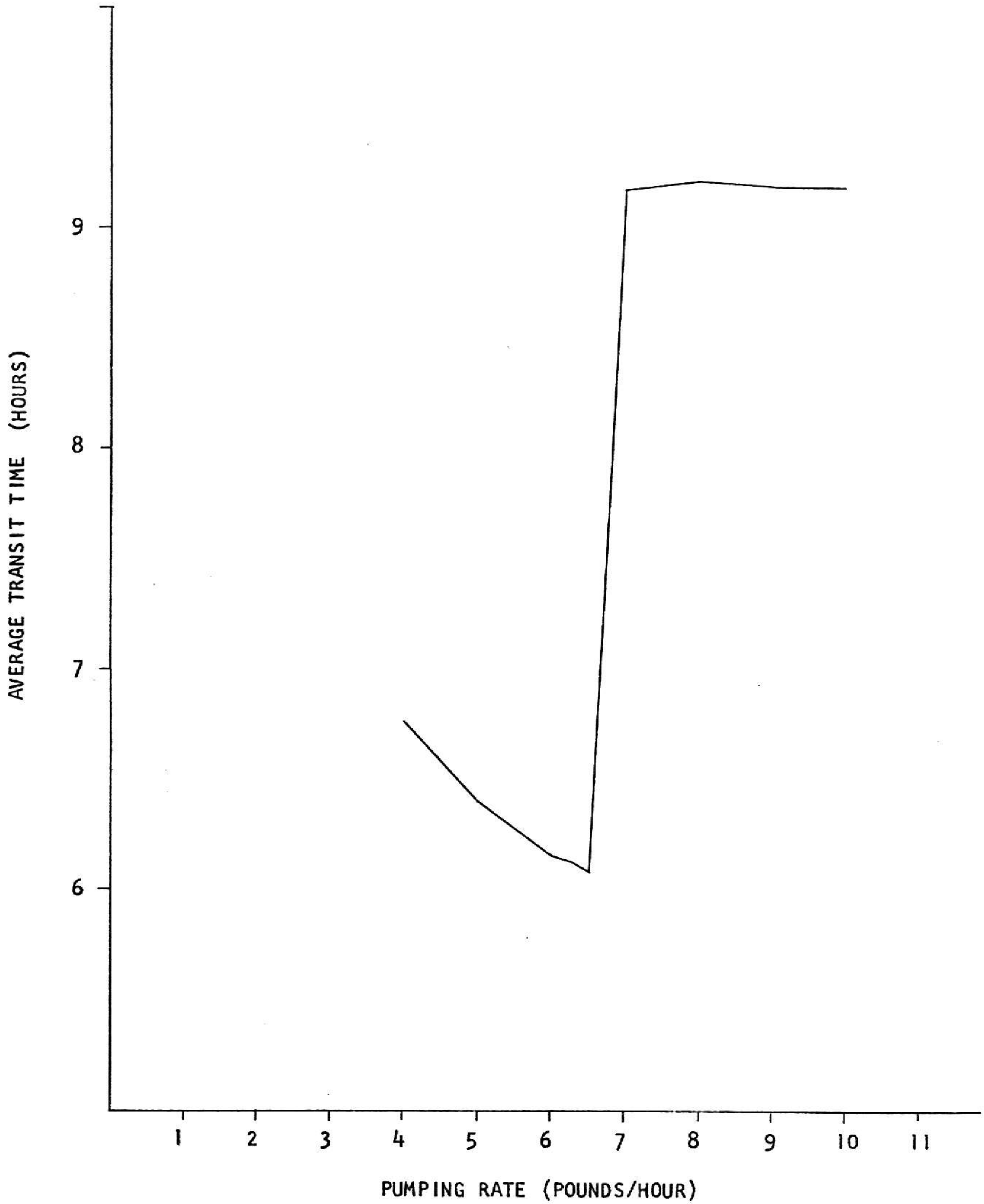


Figure 6.7. Effect of Varying Pumping Rate on Average Transit Time Till the End of First Stage in Configuration 3, Model 4.

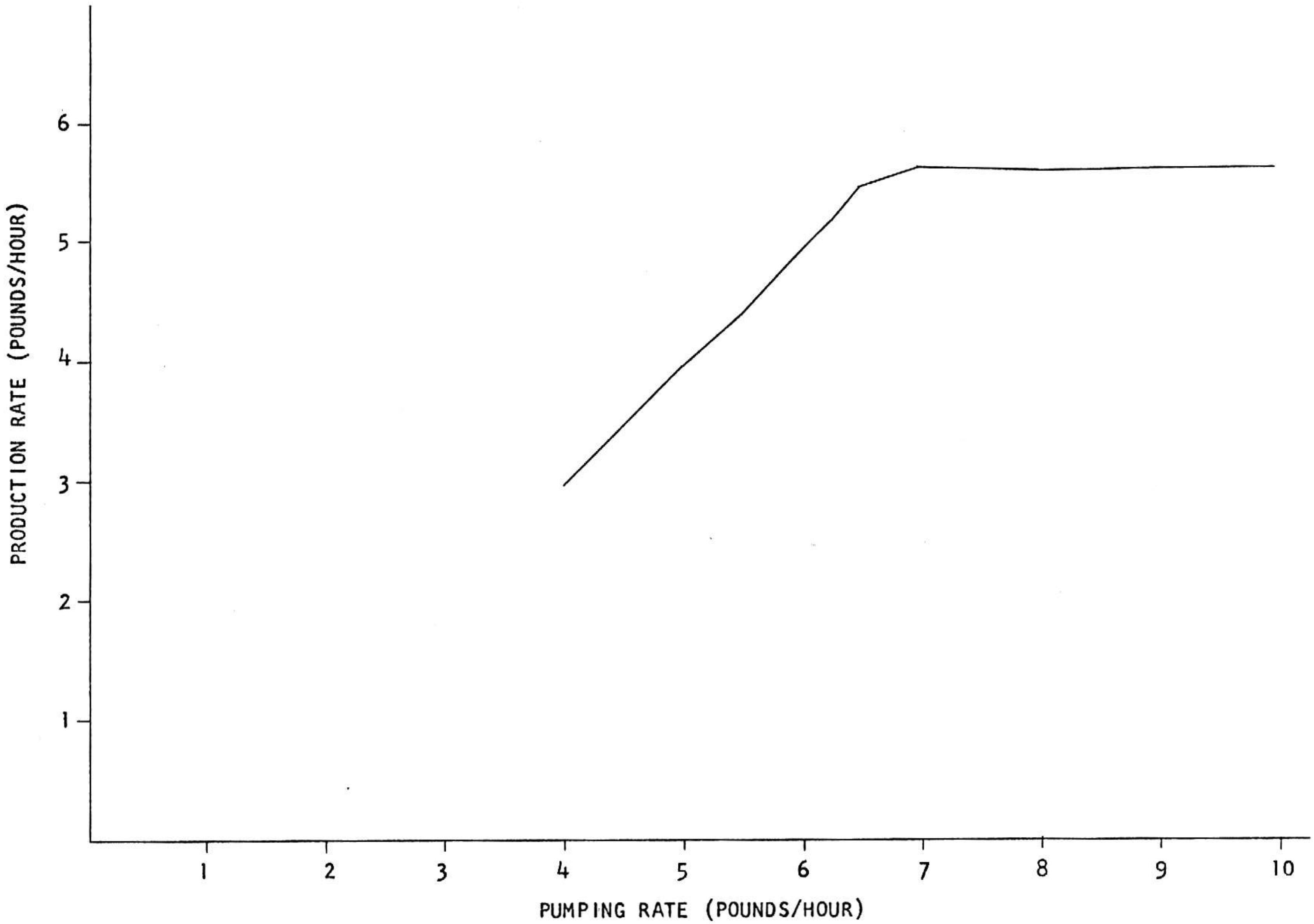


Figure 6.8. Effect of Varying Pumping Rate on Production Rate for Configuration 3, Model 4.

first stage reactor has resulted in a distinct improvement in second stage utilization.

Simulation runs were also made lasting for 1100 hours at pumping rates varying from 4 pounds/hour to 10 pounds/hour. Figure 6.7 is a plot of the variation of mean transit time till the completion of first stage reaction with the pumping rate. As in Model 3, the mean transit time shows an initial tendency to decrease till a pumping rate of 6.5 pounds/hour is reached. This is attributable to the decrease in time taken to fill the first stage reactors with the material to be processed when the pumping rate increases to 6.5 pounds/hour. There is a sudden increase at a pumping rate of 7 pounds/hour, after which the plot levels off.

The variation of production rate with pumping rate is shown in Figure 6.8. There is a steady increase till a pumping rate of 7 pounds/hour is reached after which the production rate is fairly constant.

The distribution of transit time till the end of the fourth stage reaction is the distribution of the batch production time. Respective distributions are shown at the different pumping rates in Figures 6.9 and 6.10. Figure 6.11 shows the effect of varying pumping rate on mean batch production time. The mean transit times till the end of the fourth reaction are plotted at pumping rates varying from 4 pounds/hour to 10 pounds/hour. Here also, a steady fall is observed till a pumping rate of 6.5 pounds/hour, when the mean batch time is around 7200 simulation clock units (12 hours of

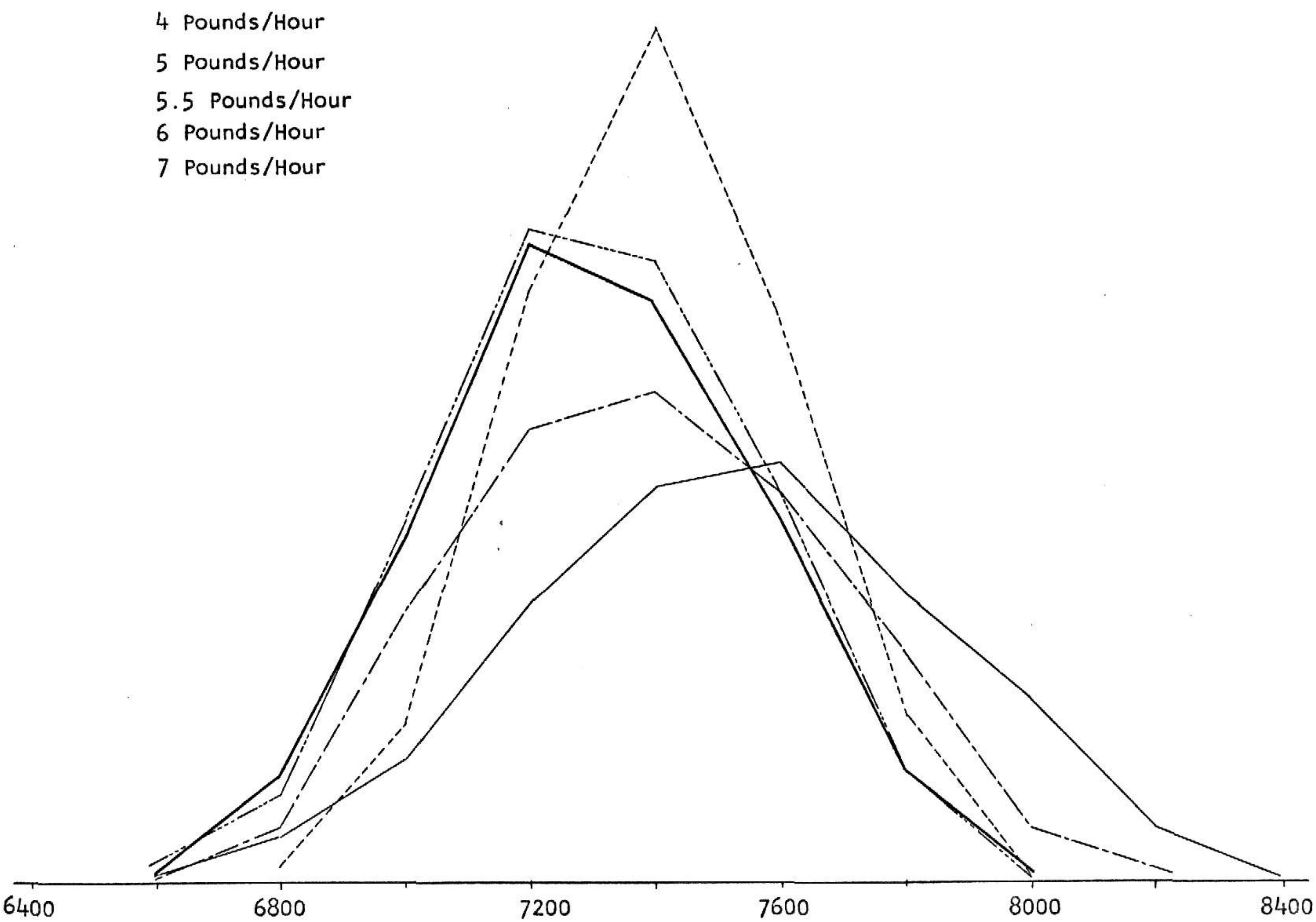


Figure 6.9. Distribution of Batch Production Time at Different Pumping Rates for Configuration 3, Model 4.

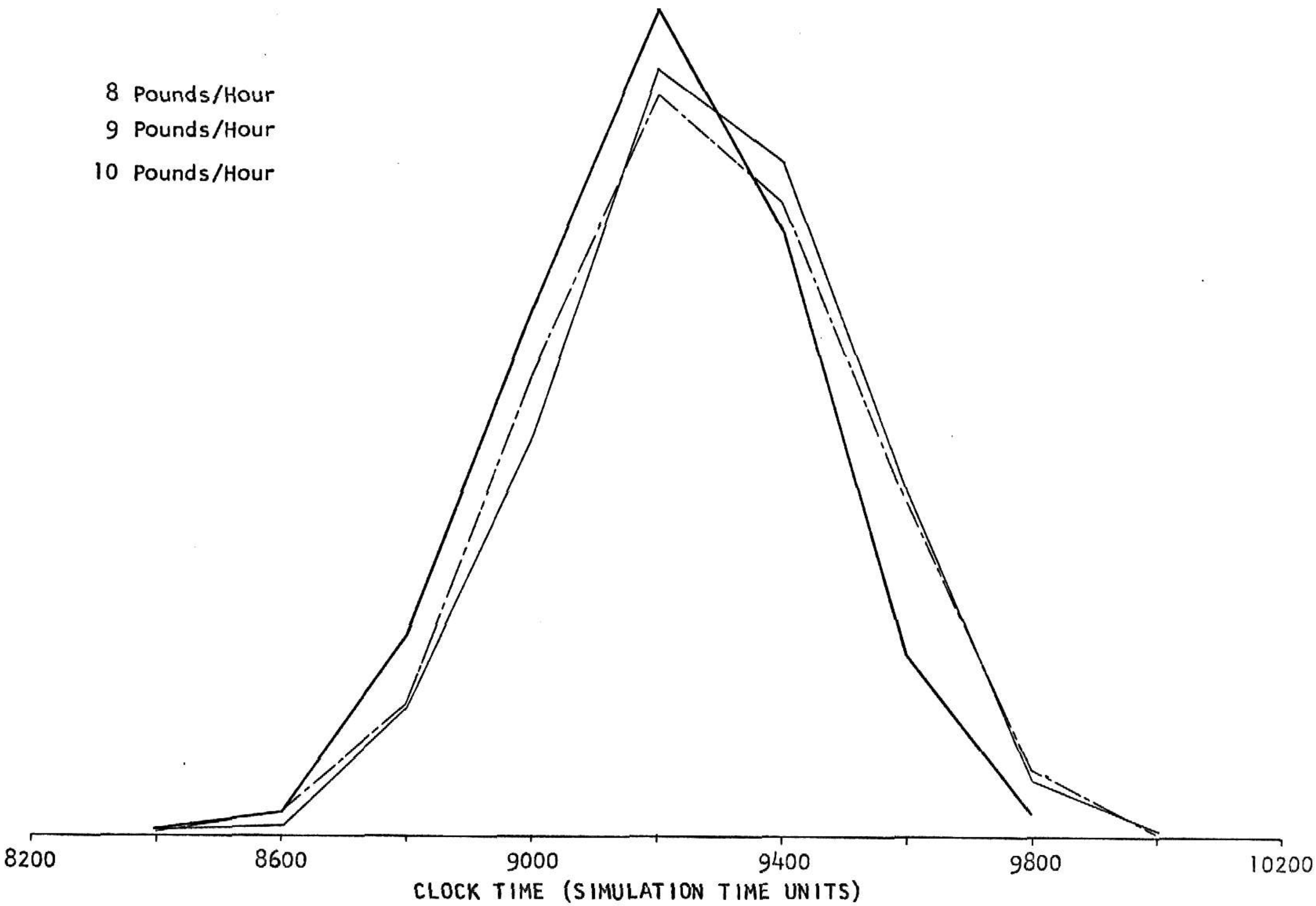


Figure 6.10. Distribution of Batch Production Time at Different Pumping Rates for Configuration 3, Model 4.

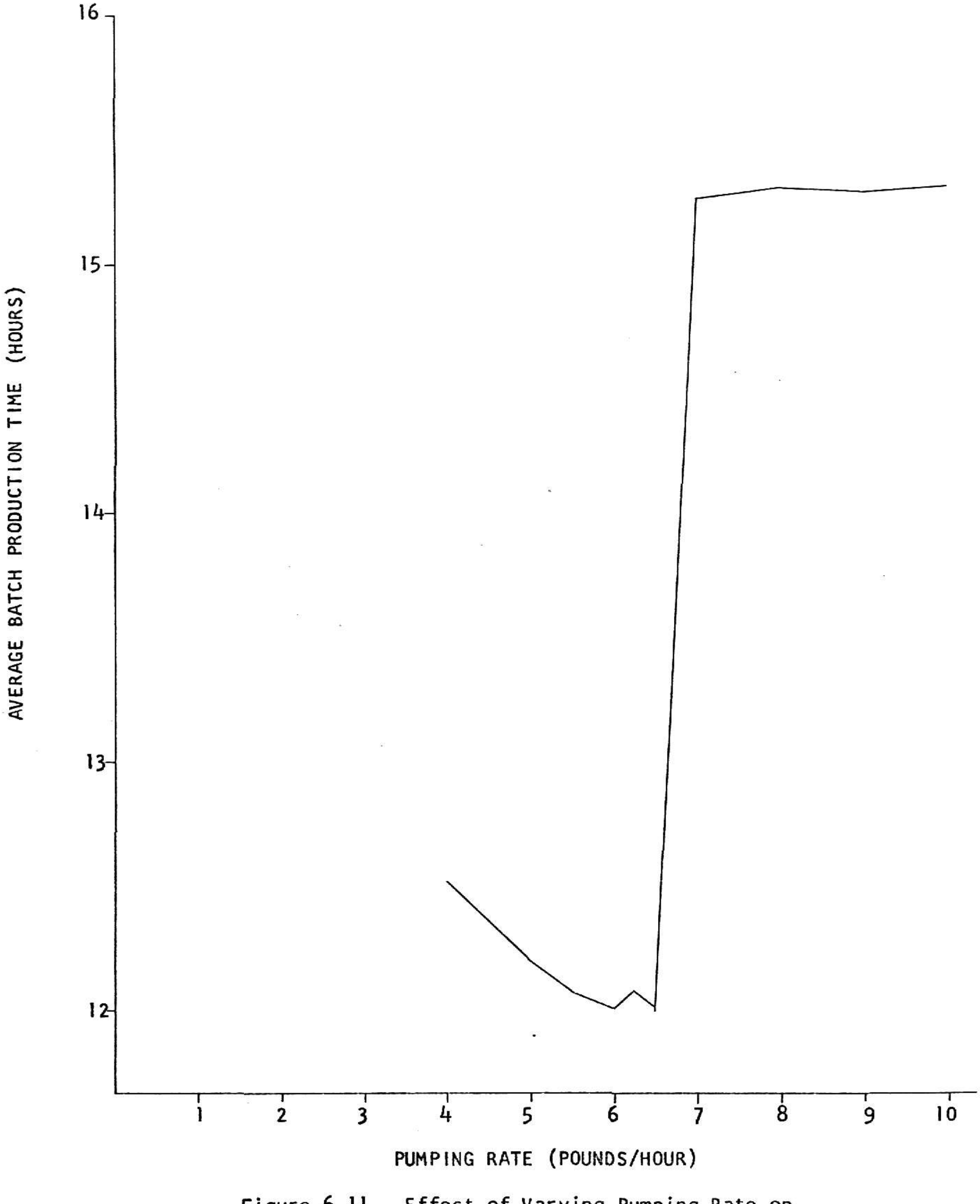


Figure 6.11. Effect of Varying Pumping Rate on the Average Batch Production Time.

real time). There is a sudden jump to 9150 simulation clock units (15.25 hours) at 7 pounds/hour pumping rate, after which there is hardly any change in the mean batch time.

The analysis of the data from this simulation makes it clear that Configuration 3 with five reactors at the first stage provides the best arrangement of the units from the point of view of production and utilization of the reactors. Table 6.2 is a comparison of the reactor utilization at the four stages in the three configurations simulated, along with the amount of material passing through each unit in 1100 hours and the average period that each batch of material spent in that unit. The uniformity of these values for the units in each stage and their magnitude do not promise anything substantial in the way of improvement in performance. The system functions best at a pumping rate of 7 pounds/hour when the production rate is 6.62 pounds/hour and the mean batch time is 9150 simulation clock units (15.25 hours).

TABLE 6.2. Comparison of Facility Statistics in Configurations 1, 2 and 3 at a Pumping Rate of 8 Pounds/Hour

Unit and Stage	CONFIGURATION 1			CONFIGURATION 2			CONFIGURATION 3		
	AVG. UTILI-ZATION	MATL. PRO-CESSED	AVG. TIME/BATCH	AVG. UTILI-ZATION	MATL. PRO-CESSED	AVG. TIME/BATCH	AVG. UTILI-ZATION	MATL. PRO-CESSED	AVG. TIME/BATCH
		# of Batches	Hours		# of Batches	Hours		# of Batches	Hours
Pump	0.703	884	0.875	0.694	795	0.875	0.834	955	0.875
Stage 1:									
Reactor 1	0.998	220	4.99	1.000	199	5.02	1.000	192	5.21
2	0.996	219	5.00	1.000	200	5.00	1.000	191	5.24
3	0.999	220	4.96	1.000	200	5.00	1.000	192	5.21
4	0.997	221	5.00	1.000	200	5.00	1.000	192	5.20
5							1.000	192	5.21
Stage 2:									
Reactor 1	0.631	219	3.16	0.853	266	3.21	0.992	319	3.11
2	0.621	218	3.14	0.856	265	3.23	0.991	319	3.11
3	0.610	219	3.07	0.852	266	3.20	0.993	319	3.12
4	0.597	220	2.98						
Stage 3:									
Reactor 1	0.395	436	1.00	0.794	795	1.00	0.954	955	1.00
2	0.398	438	1.00						
Stage 4:									
Reactor 1	0.692	436	1.75	0.712	408	1.74	0.835	477	1.75
2	0.698	438	1.75	0.678	388	1.75	0.836	478	1.75
AVG. TOTAL TIME/BATCH		10.81			10.89			11.06	

CHAPTER 7

DISCUSSION OF THE RESULTS

7.1. General

The primary objective of this study has been a complete simulation of a multistage, batchwise process. By achieving this comprehensively, useful information on the following secondary objectives was made available:

1. detection and elimination of bottlenecks in the process,
2. improving the utilization of the processing equipment and thereby improving the process,
3. providing guidelines for expansion schemes.

Three configurations involving four models were developed and their performance and response was studied during simulation runs of equal duration. In all cases, the output was obtained at 100 hour intervals during simulation runs of length 1100 hours. Each configuration was simulated under different priority rules and pumping rates. In each configuration, the best overall model was chosen in which to implement the changes and improvements. In the previous chapters, each configuration has been compared with the preceding configuration(s) from the production and utilization viewpoints. The models constructed have been stable enough to be influenced only slightly by stochastic perturbations. This fact is seen from the relatively small effect of changing the random number seeds.

7.2. Model notation

The process has four stages, each comprising a certain number of reactors in each of the configurations. The models have, therefore, been given certain notations for the purposes of convenience and identification. The notations, it is hoped, will provide the reader with a mental picture of the configurations they represent.

Model 1 of Configuration 1, therefore, becomes the 4-4-2-2 Configuration with a pulsed generator. Model 2 of Configuration 1 becomes the 4-4-2-2 Configuration. 4-3-1-2 and 5-3-1-2 are the notations given to Model 3, Configuration 3 and Model 4, Configuration 4, respectively. The notation 4-3-1-2, for instance, means that the configuration has 4 reactors at the first stage, 3 at the second, 1 at the third and 2 at the fourth. The pulsed generator has been replaced by a conventional pump which is switched on only when needed in the latter three models.

7.3. Effects of varying pumping rate

The pumping rate was varied from 4 pounds/hour to 10 pounds/hour with unit increments. Where it was deemed necessary, fractional increments were made. In general, in all the models studied, at low pumping rates, the production was considerably lower than at higher rates; a fairly high percentage of the run time was lost in waiting for the material to fill the first stage reactors. This also resulted in an increasingly lower transit times and batch times as the pumping rate was increased. However, the transition from this state to one of steadiness occured in different models at different pumping rates, the difference being, at most, unity.

The production rate curves of the three configurations at different pumping rates follow a similar pattern. Process steadiness is reached at 7 pounds/hour pumping rate.

7.4. Equipment utilization

As has been mentioned before, the two models of the 4-4-2-2 configuration exhibit the most dissimilar factors of average utilization of the different stages and the different reactors at the same stage. This is attributable only to the presence of the bias towards the left hand side of the system. Indeed, in the fourth model, the 5-3-1-2 configuration, the performance can be considered to be extremely good in that not only was the production rate noticeably higher, but also the equipment idle time was reduced to a negligibly low value.

The equipment utilization in the three configurations has been represented in Figures 7.1 through 7.5, which show respectively, the average utilization of the pump, first, second, third and the fourth stage reactors.

From the performance of these models under different operating conditions and the simulation data obtained, it can be seen that

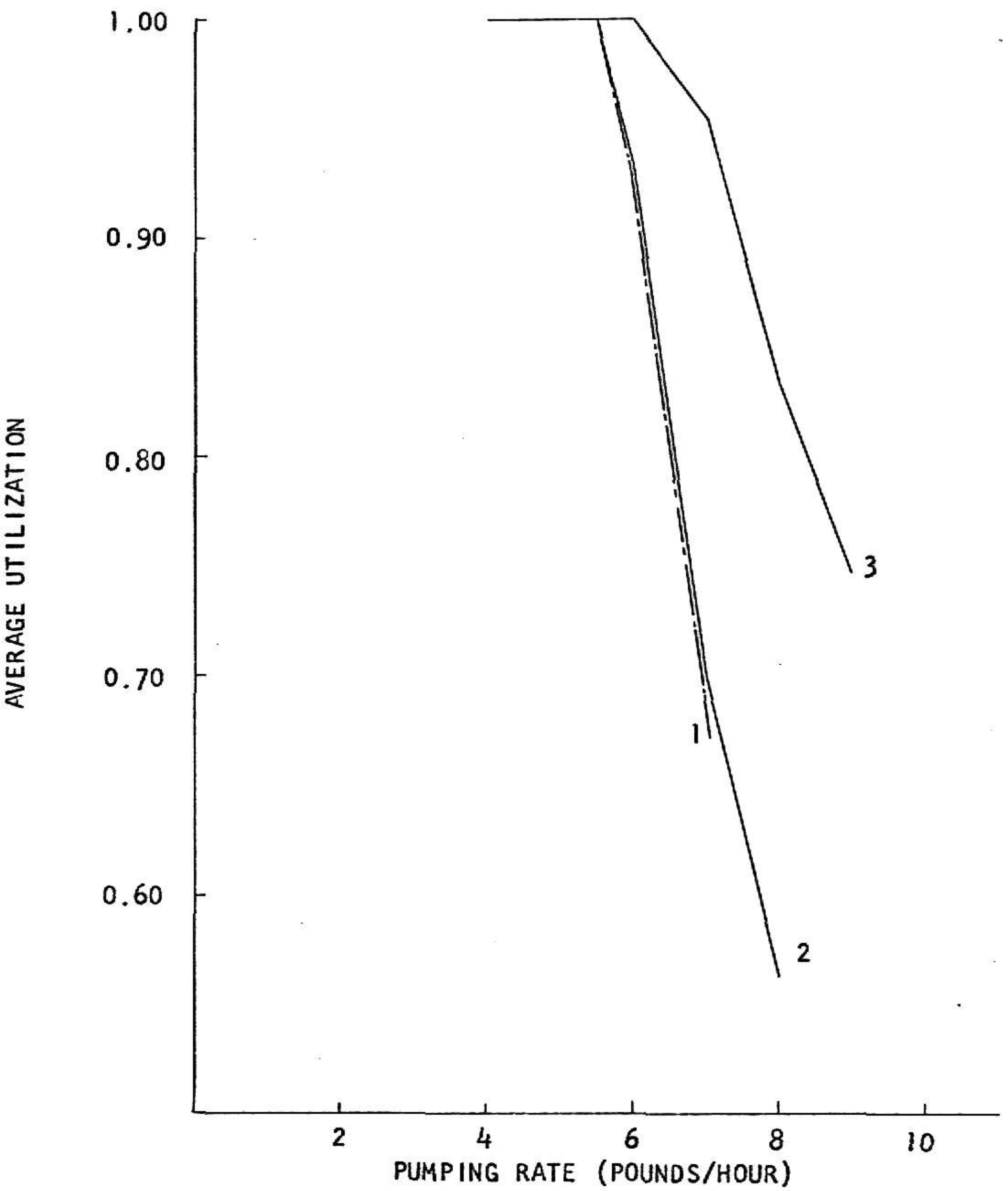


Figure 7.1. Effect of Varying Pumping Rate on Average Pump Utilizations for Configurations 1, 2 and 3.

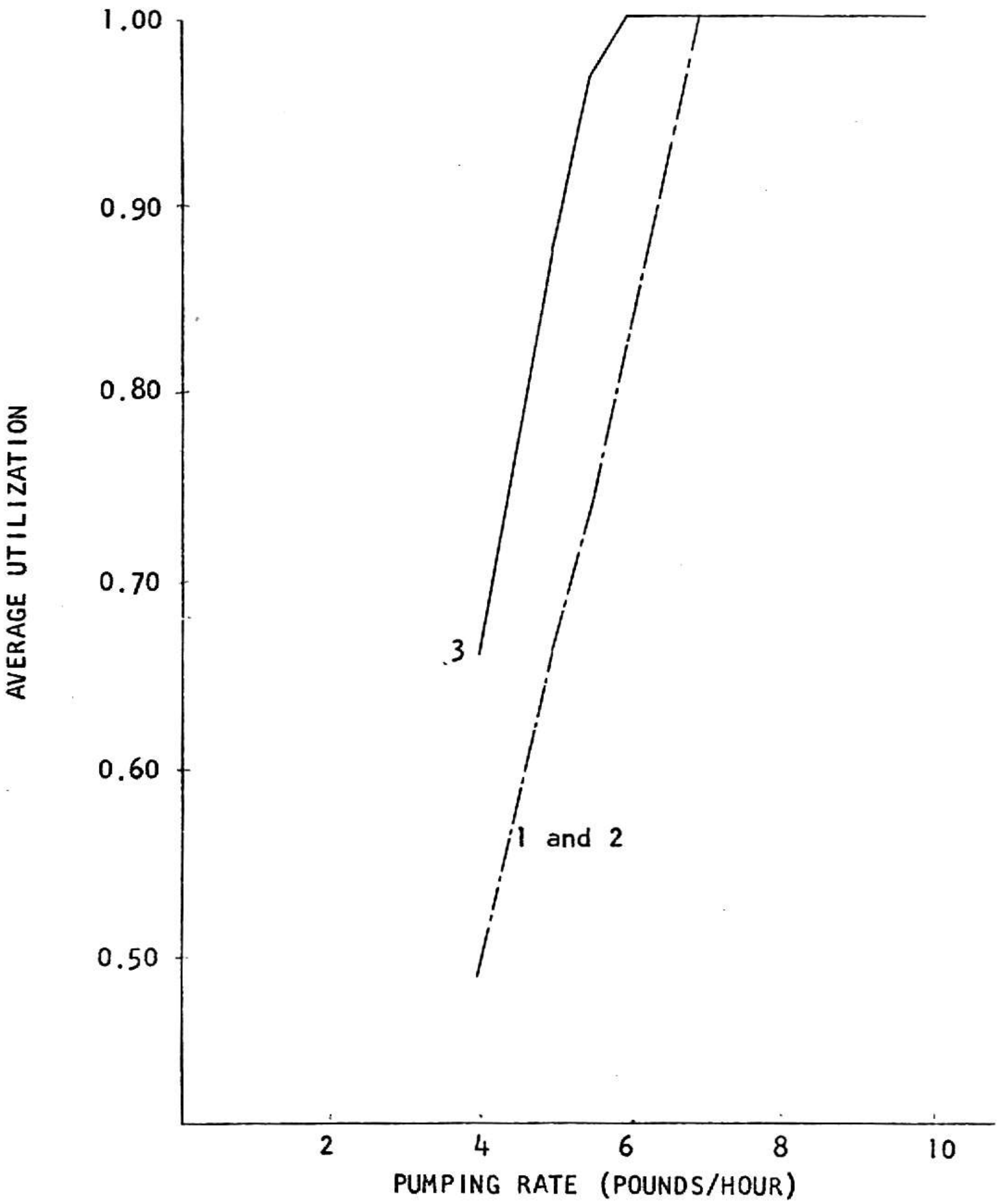


Figure 7.2. Effect of Varying Pumping Rate on Average Utilization of First Stage Reactors for Configurations 1, 2 and 3.

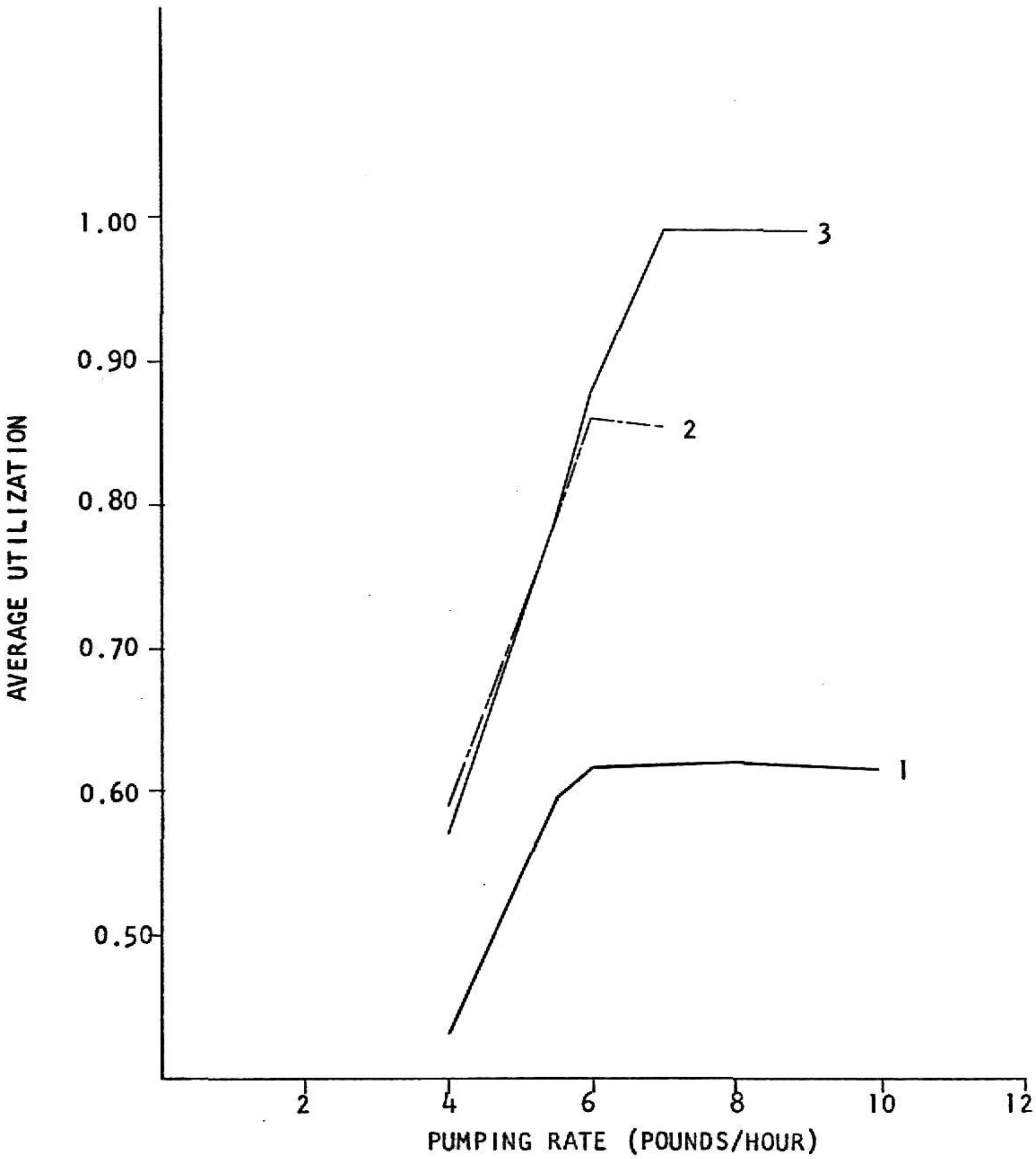


Figure 7.3. Effect of Varying Pumping Rate on Average Second Stage Utilization for Configurations 1, 2 and 3.

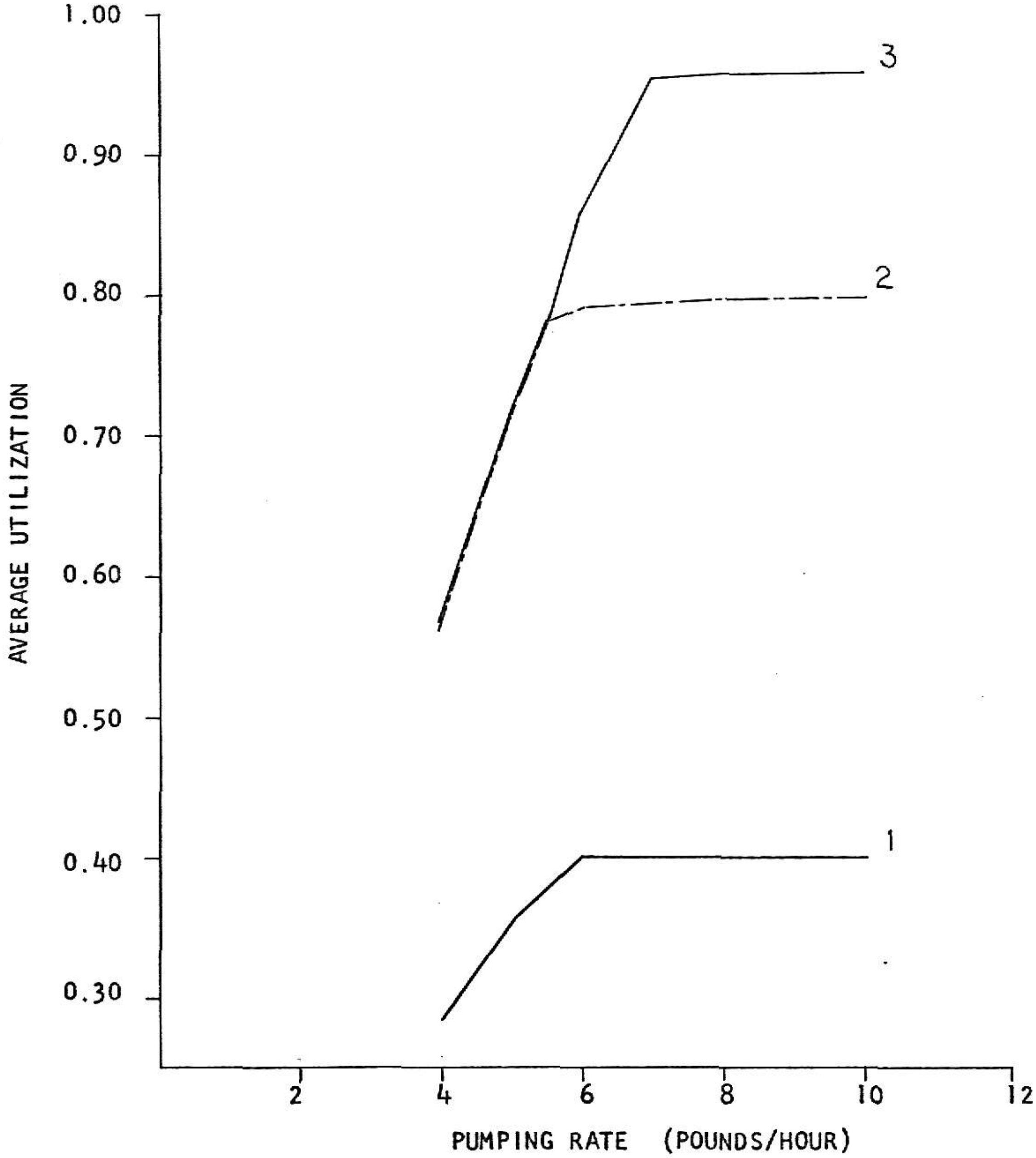


Figure 7.4. Effect of Varying Pumping Rate on Average Third Stage Utilization for Configurations 1, 2 and 3.

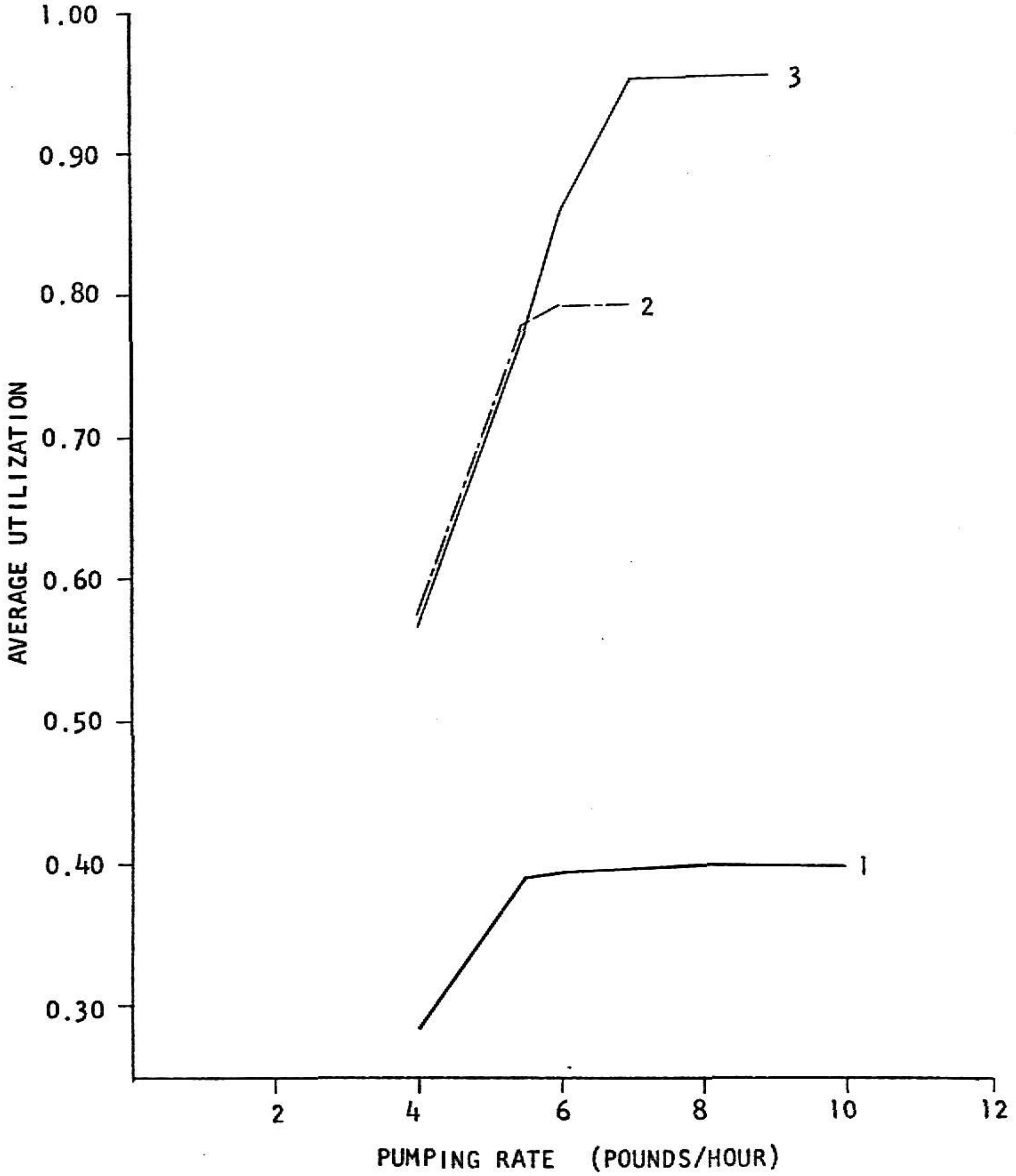


Figure 7.5. Effect of Varying Pumping Rate on Average Fourth Stage Utilization for Configurations 1, 2 and 3.

the selection of the (next) reactor is not truly unbiassed. For a relatively smaller number of reactors at any stage, the mode of selection adopted may be considered unbiassed. But as this number is increased, and thereby the number of parallel subchannels, the extreme units will tend to show a higher utilization than those in between. This may be reduced to a certain extent by limiting the number of lines catered to by the holding tank.

7.5. Guidelines for expansion programs

Any production process simulation counts among its objectives, changes in the operating policy if an increase in production is called for. This may be achieved by replacing the existing processing units with those of greater capacity. This involves a number of economic considerations and organizational policies. This study has been undertaken on the assumption that the unit capacities remain unchanged at 7 pounds. The only alternative course of action therefore, is to increase the number of parallel production lines.

The 5-3-1-2 configuration as such does not leave much to be desired either in the uniformity or in the extent of equipment utilization. On the basis of the high degree of utilization at three of the four stages, it may be stated with reasonable certainty that the addition of a sixth first stage reactor will lower the productive utilization at this stage and raise it at the next stage. However, since the second stage is almost always busy, this change may result in a delay at this point in the process. It will, hence, necessitate the addition of a fourth second stage reactor, which in turn may require another third stage reactor.

It is, therefore, clear that the 5-3-1-2 configuration, which employs a pump, two holding tanks and 11 reactors in the four stages, cannot be improved upon without making elaborate changes in the configuration. Moreover, the 5-3-1-2 configuration compares very favorably with the original model, the 4-4-2-2 configuration with a pump, four holding tanks and 12 reactors in four stages, and is, therefore, the recommended configuration for this multistage batch production process.

CHAPTER 8

CONCLUSION

A multistage batch production process has been simulated for a period of 1100 hours on an IBM 360/50 computer using GPSS/360 simulation language. The most important factor to be elicited from the simulation is the manner in which to arrange the equipment units to obtain a smooth production process.

A significant feature to come to light is the selection of the path of flow from stage to stage. The absence of the correct mode of selection will adversely affect the process.

The assumption regarding an infinite raw materials source has helped the process attain steadiness of operation within 200 hours of start up. The processing times at the four stages being distributed uniformly within the respective ranges provided, the only variable in this process is the pumping rate. This has different effects on the characteristics of the operation of the process. The production rate and the cumulative production show a steady upward trend before levelling off and becoming stable. The average utilization factors of the different equipment units are high at the recommended pumping rate.

Some of the other features to come to light are the balanced nature of the configuration denoted by 5-3-1-2; the absence of any bottleneck in the process; the uniformity of equipment utilization.

The use of GPSS/360 as the programming language had its advantages. It is a very compact and convenient programming language in that it is possible to pictorially represent the process using the GPSS/360 block diagrams. Modifications and variations are easily implemented.

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APPENDIX A

Computer Program for Configuration 1, Model 1.

```
BLOCK
NUMBER   *LOC     OPERATION  A,B,C,D,E,F,G                  COMMENTS
                  SIMULATE
                  STORAGE    S1-S4,14
                1 TABLE      M1,4500,100,60
                2 TABLE      M1,4500,100,60
                3 TABLE      M1,4500,100,60
                4 TABLE      M1,4500,100,60
                5 TABLE      M1,5000,100,40
                6 TABLE      M1,5000,100,40
                7 TABLE      M1,7000,100,40
                8 TABLE      M1,7000,100,40
                9 TABLE      M1,7000,100,40
1                 GENERATE   75,,,,,4,F      GENERATE MATERIAL AT THE RATE OF
         *                                   8 POUNDS/HOUR
         *****
         *****                               CONFIGURATION  1 ,  MODEL  1
         *****
2          START  TRANSFER   ALL,LEFT,TERM,5
3           LEFT  ENTER      1,1
4                 MARK
5                 TEST NE    S1,7,ACD
6                 TEST E     S1,14,TERM
7            ACD  TRANSFER   ,AAAA
8          RIGHT  ENTER      2,1
9                 MARK
10                TEST NE    S2,7,BCD
11                TEST E     S2,14,TERM
12           BCD  TRANSFER   ,BBBB
13          TERM  TERMINATE
         *****
         *****      LEFT HALF OF THE SYSTEM
         *****
14          AAAA  TRANSFER   BOTH,LLA,LRA    MOVE MATERIAL TO ONE OF THE TWO
         *                                   REACTORS, PRIORITY TO THE LEFT REACTO
15           LLA  SEIZE      6
16                LEAVE      1,7
17          LADI  ADVANCE    3000,200        PROCESSING AT  FIRST STAGE REACTORS
18                SEIZE      7
19                RELEASE    6
20                ADVANCE    1800,150        PROCESSING AT SECOND STAGE REACTORS
21                TABULATE   1               TRANSIT TIME DISTRIBUTION AT END OF
         *                                   SECOND STAGE REACTORS
22                SEIZE      10
23                RELEASE    7
24                TRANSFER   ,TTTT
25           LRA  SEIZE      8
26                LEAVE      1,7
27         LADII  ADVANCE    3000,200        PROCESSING AT  FIRST STAGE REACTORS
28                SEIZE      9
29                RELEASE    8
30                ADVANCE    1800,150        PROCESSING AT SECOND STAGE REACTORS
31                TABULATE   2               TRANSIT TIME DISTRIBUTION AT END OF
         *                                   SECOND STAGE REACTORS
32                SEIZE      10
33                RELEASE    9
34                TRANSFER   ,TTTT
```

```
        *****
35        TTTT ADVANCE    600,50          PROCESSING AT THIRD STAGE REACTORS
36             TABULATE   5               TRANSIT TIME DISTRIBUTION AT END OF
        *                                 THIRD STAGE REACTOR
37             ENTER      3,7
38             RELEASE    10
39             TABULATE   3
40             SEIZE      11
41             LEAVE      3,7
42             ADVANCE    1050,100        PROCESSING AT FOURTH STAGE REACTORS
43             TABULATE   7               TRANSIT TIME DISTRIBUTION AT END OF
        *                                 FOURTH STAGE REACTOR
        *****
44             ENTER      5,7
45             RELEASE    11
46             TRANSFER   ,TAB
        *****
        *****     RIGHT HALF OF THE SYSTEM
        *****
47        EEBB TRANSFER   BOTH,RLB,RRB    MOVE MATERIAL TO ONE OF THE TWO
        *                                 REACTORS, PRIORITY TO THE LEFT REACTC
48         RLB SEIZE      12
49             LEAVE      2,7
50        RADI ADVANCE    3000,200        PROCESSING AT  FIRST STAGE REACTORS
51             SEIZE      13
52             RELEASE    12
53             ADVANCE    1800,150        PROCESSING AT SECOND STAGE REACTORS
54             TABULATE   3               TRANSIT TIME DISTRIBUTION AT END OF
        *                                 SECOND STAGE REACTORS
55             TABULATE   2
56             SEIZE      16
57             RELEASE    13
58             TRANSFER   ,SSSS
59         RRB SEIZE      14
60             LEAVE      2,7
61       RADII ADVANCE    3000,200        PROCESSING AT  FIRST STAGE REACTORS
62             SEIZE      15
63             RELEASE    14
64             ADVANCE    1800,150        PROCESSING AT SECOND STAGE REACTORS
65             TABULATE   4               TRANSIT TIME DISTRIBUTION AT END OF
        *                                 SECOND STAGE REACTORS
66             TABULATE   2
67             SEIZE      16
68             RELEASE    15
69             TRANSFER   ,SSSS
        *****
70        SSSS ADVANCE    600,50          PROCESSING AT THIRD STAGE REACTORS
71             TABULATE   6               TRANSIT TIME DISTRIBUTION AT END OF
        *                                 THIRD STAGE REACTOR
72             ENTER      4,7
73             RELEASE    16
74             TABULATE   4
75             SEIZE      17
76             LEAVE      4,7
77             ADVANCE    1050,100        PROCESSING AT FOURTH STAGE REACTORS
78             TABULATE   8               TRANSIT TIME DISTRIBUTION AT END OF
        *                                 FOURTH STAGE REACTOR
```

```
        *****
79                ENTER       5,7
80                RELEASE     17
81                TRANSFER    ,TAB
        *****
        *****       END CF THE LINE
        *****
82            TAB TABULATE    9                  BATCH TIME DISTRIBUTION
83            END TERMINATE
84                GENERATE    60000
85                TERMINATE   1
                  START       1                  RUN SIMULATION FOR 100 HOURS
                  RESET
                  START       10                 RUN SIMULATION FOR 1000 HOURS
                  END
```

APPENDIX B

Computer Program for Configuration 1, Model 2.

```
BLOCK
NUMBER   *LOC    OPERATION  A,B,C,D,E,F,G             COMMENTS
                 SIMULATE
                 STORAGE    S1-S4,14
               1 TABLE      M1,4500,100,60
               2 TABLE      M1,4500,100,60
               3 TABLE      M1,4500,100,60
               4 TABLE      M1,4500,100,60
               5 TABLE      M1,5000,100,40
               6 TABLE      M1,5000,100,40
               7 TABLE      M1,7000,100,40
               8 TABLE      M1,7000,100,40
               9 TABLE      M1,7000,100,40
1                GENERATE   ,,,4,,4,F     GENERATE 4 TRANSACTIONS
         *                                WITH A WEIGHT OF 7 POUNDS EACH
         *****
         *****                            CONFIGURATION  1 ,  MODEL  2
         *****
2         START  SEIZE      PUMP
3                ADVANCE    525           PUMPING TIME FOR 7 POUNDS OF MATERIAL
         *                                AT THE RATE OF 8 POUNDS/HOUR
4                TRANSFER   .500,RIGHT,LEFT
5          LEFT  TRANSFER   BOTH,SONE,STWO
6         RIGHT  TRANSFER   BOTH,STWO,SONE
7          SONE  ENTER      1,7
8                MARK
9                TRANSFER   ,AAAA
10         STWO  ENTER      2,7
11               MARK
12               TRANSFER   ,BBBB
         *****
         *****    LEFT HALF OF THE SYSTEM
         *****
13         AAAA  TRANSFER   BOTH,LLA,LRA  MOVE MATERIAL TO ONE OF THE TWO
         *                                REACTORS, PRIORITY TO THE LEFT REACTO
14          LLA  SEIZE      6
15               LEAVE      1,7
16         LADI  ADVANCE    3000,200      PROCESSING AT  FIRST STAGE REACTORS
17               SEIZE      7
18               RELEASE    6
19               ADVANCE    1800,150      PROCESSING AT SECOND STAGE REACTORS
20               TABULATE   1             TRANSIT TIME DISTRIBUTION AT END OF
         *                                SECOND STAGE REACTORS
21               SEIZE      10
22               RELEASE    7
23               TRANSFER   ,TTTT
24          LRA  SEIZE      8
25               LEAVE      1,7
26        LADII  ADVANCE    3000,200      PROCESSING AT  FIRST STAGE REACTORS
27               SEIZE      9
28               RELEASE    8
29               ADVANCE    1800,150      PROCESSING AT SECOND STAGE REACTORS
30               TABULATE   2             TRANSIT TIME DISTRIBUTION AT END OF
         *                                SECOND STAGE REACTORS
31               SEIZE      10
32               RELEASE    9
33               TRANSFER   ,TTTT
```

```
       *****
34       TTTT ADVANCE    600,50          PROCESSING AT THIRD STAGE REACTORS
35            TABULATE   5               TRANSIT TIME DISTRIBUTION AT END OF
       *                                 THIRD STAGE REACTOR
36            ENTER      3,7
37            RELEASE    10
38            TABULATE   3
39            SEIZE      11
40            LEAVE      3,7
41            ADVANCE    1050,100        PROCESSING AT FOURTH STAGE REACTORS
42            TABULATE   7               TRANSIT TIME DISTRIBUTION AT END OF
       *                                 FOURTH STAGE REACTOR
       *****
43            ENTER      5,7
44            RELEASE    11
45            TRANSFER   ,TAB
       *****
       *****   RIGHT HALF OF THE SYSTEM
       *****
46       EEBB TRANSFER   BOTH,RLB,RRB    MOVE MATERIAL TO ONE OF THE TWO
       *                                 REACTORS, PRIORITY TO THE LEFT REACT(
47        RLB SEIZE      12
48            LEAVE      2,7
49       RADI ADVANCE    3000,200        PROCESSING AT  FIRST STAGE REACTORS
50            SEIZE      13
51            RELEASE    12
52            ADVANCE    1800,150        PROCESSING AT SECOND STAGE REACTORS
53            TABULATE   3               TRANSIT TIME DISTRIBUTION AT END OF
       *                                 SECOND STAGE REACTORS
54            TABULATE   2
55            SEIZE      16
56            RELEASE    13
57            TRANSFER   ,SSSS
58        RRB SEIZE      14
59            LEAVE      2,7
60      RADII ADVANCE    3000,200        PROCESSING AT  FIRST STAGE REACTORS
61            SEIZE      15
62            RELEASE    14
63            ADVANCE    1800,150        PROCESSING AT SECOND STAGE REACTORS
64            TABULATE   4               TRANSIT TIME DISTRIBUTION AT END OF
       *                                 SECOND STAGE REACTORS
65            TABULATE   2
66            SEIZE      16
67            RELEASE    15
68            TRANSFER   ,SSSS
       *****
69       SSSS ADVANCE    600,50          PROCESSING AT THIRD STAGE REACTORS
70            TABULATE   6               TRANSIT TIME DISTRIBUTION AT END OF
       *                                 THIRD STAGE REACTOR
71            ENTER      4,7
72            RELEASE    16
73            TABULATE   4
74            SEIZE      17
75            LEAVE      4,7
76            ADVANCE    1050,100        PROCESSING AT FOURTH STAGE REACTORS
77            TABULATE   8               TRANSIT TIME DISTRIBUTION AT END OF
       *                                 FOURTH STAGE REACTOR
```

```
          *****
78                  ENTER       5,7
79                  RELEASE     17
80                  TRANSFER    ,TAB
          *****
          *****       END OF THE LINE
          *****
81              TAB TABULATE    9                  BATCH TIME DISTRIBUTION
82              END TERMINATE
83                  GENERATE    60000
84                  TERMINATE   1
                    START       1                  RUN SIMULATION FOR 100 HOURS
                    RESET
                    START       10                 RUN SIMULATION FOR 1000 HOURS
                    END
```

APPENDIX C

Computer Program for Configuration 2, Model 3.

```
BLOCK
NUMBER   *LOC    OPERATION  A,B,C,D,E,F,G            COMMENTS
                 SIMULATE
                 STORAGE    S1,28/S2,14
               1 TABLE      M1,3200,100,60
               2 TABLE      M1,3200,100,60
               3 TABLE      M1,3200,100,60
               4 TABLE      M1,3200,100,60
               5 TABLE      M1,4500,100,60
               6 TABLE      M1,4500,100,60
               7 TABLE      M1,4500,100,60
               8 TABLE      M1,5000,100,60
               9 TABLE      M1,6500,100,60
              10 TABLE      M1,6500,100,60
            LAST TABLE      M1,6500,100,60
         *                   CONFIGURATION  2 ,  MODEL  3
1                GENERATE   ,,,4,,6,F
2          START SEIZE      PUMP
3                MARK
4                ADVANCE    525
         *                   SEND 7 POUNDS OF MATERIAL TO THE HOLDING TANK
5                ENTER      1,7
6                RELEASE    PUMP
            XXXX STARTMACRO
                 ASSIGN     1,#A
                 LEAVE      1,7
                 SPLIT      1,START    SWITCHING DEVICE TO START THE PUMP
                 ADVANCE    3000,200   PROCESSING AT FIRST STAGE
                 TABULATE   #B
                 TRANSFER   ,BBBB
                 ENDMACRO
            YYYY STARTMACRO
                 ASSIGN     2,#A
                 RELEASE    *1
                 ADVANCE    1800,150   PROCESSING AT SECOND STAGE
                 TABULATE   #B
                 TRANSFER   ,CCCC
                 ENDMACRO
            FOUR STARTMACRO
                 ASSIGN     4,#A
                 LEAVE      2,7
                 ADVANCE    1050,100   PROCESSING AT FOURTH STAGE
                 TABULATE   #B
                 TRANSFER   ,FINAL
                 ENDMACRO
         *                   PROVISION OF EQUAL PROBABILITY OF SELECTION
         *                   OF PATH OF FLOW
7           AAAA TRANSFER   .500,ONEB,ONEA
8           ONEA TRANSFER   ALL,AONE,DONE,7
9           ONEB TRANSFER   ALL,AAONE,DDONE,7
10          AONE SEIZE      4
            XXXX MACRO      4,1
11               ASSIGN     1,4
12               LEAVE      1,7
13               SPLIT      1,START
14               ADVANCE    3000,200
15               TABULATE   1
```

```
16              TRANSFER    ,BBBB
17        BONE  SEIZE       5
          XXXX  MACRO       5,2
18              ASSIGN      1,5
19              LEAVE       1,7
20              SPLIT       1,START
21              ADVANCE     3000,200
22              TABULATE    2
23              TRANSFER    ,BBBB
24        CONE  SEIZE       6
          XXXX  MACRO       6,3
25              ASSIGN      1,6
26              LEAVE       1,7
27              SPLIT       1,START
28              ADVANCE     3000,200
29              TABULATE    3
30              TRANSFER    ,BBBB
31        DONE  SEIZE       7
          XXXX  MACRO       7,4
32              ASSIGN      1,7
33              LEAVE       1,7
34              SPLIT       1,START
35              ADVANCE     3000,200
36              TABULATE    4
37              TRANSFER    ,BBBB
38       AAONE  SEIZE       7
          XXXX  MACRO       7,4
39              ASSIGN      1,7
40              LEAVE       1,7
41              SPLIT       1,START
42              ADVANCE     3000,200
43              TABULATE    4
44              TRANSFER    ,BBBB
45       BBONE  SEIZE       6
          XXXX  MACRO       6,3
46              ASSIGN      1,6
47              LEAVE       1,7
48              SPLIT       1,START
49              ADVANCE     3000,200
50              TABULATE    3
51              TRANSFER    ,BBBB
52       CCONE  SEIZE       5
          XXXX  MACRO       5,2
53              ASSIGN      1,5
54              LEAVE       1,7
55              SPLIT       1,START
56              ADVANCE     3000,200
57              TABULATE    2
58              TRANSFER    ,BBBB
59       DDONE  SEIZE       4
          XXXX  MACRO       4,1
60              ASSIGN      1,4
61              LEAVE       1,7
62              SPLIT       1,START
63              ADVANCE     3000,200
64              TABULATE    1
65              TRANSFER    ,BBBB
```

```
        *                   PROVISION OF EQUAL PROBABILITY OF SELECTION
        *                   OF PATH OF FLOW
66        BBBB TRANSFER  .500,BRRR,BLLL
67        BLLL TRANSFER  ALL,EONE,GONE,6
68        BRRR TRANSFER  ALL,GGONE,EEONE,6
69        EONE SEIZE     8
          YYYY MACRO     8,5
70             ASSIGN    2,8
71             RELEASE   *1
72             ADVANCE   1800,150
73             TABULATE  5
74             TRANSFER  ,CCCC
75        FONE SEIZE     9
          YYYY MACRO     9,6
76             ASSIGN    2,9
77             RELEASE   *1
78             ADVANCE   1800,150
79             TABULATE  6
80             TRANSFER  ,CCCC
81        GONE SEIZE     10
          YYYY MACRO     10,7
82             ASSIGN    2,10
83             RELEASE   *1
84             ADVANCE   1800,150
85             TABULATE  7
86             TRANSFER  ,CCCC
87       GGONE SEIZE     10
          YYYY MACRO     10,7
88             ASSIGN    2,10
89             RELEASE   *1
90             ADVANCE   1800,150
91             TABULATE  7
92             TRANSFER  ,CCCC
93       FFONE SEIZE     9
          YYYY MACRO     9,6
94             ASSIGN    2,9
95             RELEASE   *1
96             ADVANCE   1800,150
97             TABULATE  6
98             TRANSFER  ,CCCC
99       EEONE SEIZE     8
          YYYY MACRO     8,5
100            ASSIGN    2,8
101            RELEASE   *1
102            ADVANCE   1800,150
103            TABULATE  5
104            TRANSFER  ,CCCC
105       CCCC SEIZE     11
106            RELEASE   *2
107            ADVANCE   600,50       PROCESSING AT THIRD STAGE
108            ENTER     2,7
109            RELEASE   11
110            TABULATE  8
111            TRANSFER  BOTH,LFOR,RFOR
112       LFOR SEIZE     12
          FOUR MACRO     12,9
113            ASSIGN    4,12
```

```
114          LEAVE      2,7
115          ADVANCE    1050,100
116          TABULATE   9
117          TRANSFER   ,FINAL
118     RFOR SEIZE      13
        FOUR MACRO      13,10
119          ASSIGN     4,13
120          LEAVE      2,7
121          ADVANCE    1050,100
122          TABULATE   10
123          TRANSFER   ,FINAL
124    FINAL ENTER      3,7
125          RELEASE    *4
126          TABULATE   LAST
127      END TERMINATE
128          GENERATE   60000
129          TERMINATE  1
             START      1
             RESET
             START      10
             CLEAR
             END
```

APPENDIX D

Computer Program for Configuration 3, Model 4

```
BLOCK
NUMBER   *LOC   OPERATION   A,B,C,D,E,F,G          COMMENTS
                SIMULATE
                STORAGE     S1,28/S2,14
             1  TABLE       M1,3200,100,60
             2  TABLE       M1,3200,100,60
             3  TABLE       M1,3200,100,60
             4  TABLE       M1,3200,100,60
             5  TABLE       M1,3200,100,60
             6  TABLE       M1,4500,100,60
             7  TABLE       M1,4500,100,60
             8  TABLE       M1,4500,100,60
             9  TABLE       M1,6500,100,60
            10  TABLE       M1,6500,100,60
            11  TABLE       M1,6500,100,60
          LAST  TABLE       M1,6500,100,60
             1  VARIABLE    525
         *                              CONFIGURATION  3 ,  MODEL  4
1               GENERATE    ,,,4,,6,F
         *                              GENERATE FOUR TRANSACTIONS TO START
         *                              THE SIMULATION
2        START  SEIZE       PUMP
3               MARK
4               ADVANCE     V1
         *                              SEND 7 POUNDS OF MATERIAL TO HOLDING
         *                              TANK AT FIRST LEVEL AT 8 POUNDS/HOUR .
5               ENTER       1,7
6               RELEASE     PUMP
          XXXX  STARTMACRO
                ASSIGN      1,#A
                LEAVE       1,7
                SPLIT       1,START     SWITCHING DEVICE TO START PUMP
                ADVANCE     3000,200    PROCESS MATERIAL AT FIRST STAGE
                TABULATE    #B
                TRANSFER    ,BBBB
                ENDMACRO
          YYYY  STARTMACRO
                ASSIGN      2,#A
                RELEASE     *1
                ADVANCE     1800,150    PROCESSING THE MATERIAL AT SECOND STAGE
                TABULATE    #B
                TRANSFER    ,CCCC
                ENDMACRO
          FOUR  STARTMACRO
                ASSIGN      4,#A
                LEAVE       2,7
                ADVANCE     1050,100    PROCESSING THE MATERIAL AT FOURTH STAGE
                TABULATE    #B
                TRANSFER    ,FINAL
                ENDMACRO
7         AAAA  TRANSFER    .500,ONEB,ONEA
         *                              SELECT THE SUBSEQUENT PATH OF FLOW
         *                              ON THE BASIS OF AN EQUAL PROBABILITY
         *                              ASSIGNED TO EACH POSSIBLE PATH .
8         CNEA  TRANSFER    ALL,XONE,DONE,7
9         CNEB  TRANSFER    ALL,AAONE,XXONE,7
10        XONE  SEIZE       3
```

```
        XXXX MACRO      3,1
.11          ASSIGN     1,3
12           LEAVE      1,7
13           SPLIT      1,START
14           ADVANCE    3000,200
15           TABULATE   1
16           TRANSFER   ,BBBB
17      AONE SEIZE      4
        XXXX MACRO      4,2
18           ASSIGN     1,4
19           LEAVE      1,7
20           SPLIT      1,START
21           ADVANCE    3000,2CO
22           TABULATE   2
23           TRANSFER   ,BBBB
24      BONE SEIZE      5
        XXXX MACRO      5,3
25           ASSIGN     1,5
26           LEAVE      1,7
27           SPLIT      1,START
28           ADVANCE    3000,200
29           TABULATE   3
30           TRANSFER   ,BBBB
31      CONE SEIZE      6
        XXXX MACRO      6,4
32           ASSIGN     1,6
33           LEAVE      1,7
34           SPLIT      1,START
35           ADVANCE    3000,200
36           TABULATE   4
37           TRANSFER   ,BBBB
38      DONE SEIZE      7
        XXXX MACRO      7,5
39           ASSIGN     1,7
40           LEAVE      1,7
41           SPLIT      1,START
42           ADVANCE    3000,2CO
43           TABULATE   5
44           TRANSFER   ,BBBB
45     AAONE SEIZE      7
        XXXX MACRO      7,5
46           ASSIGN     1,7
47           LEAVE      1,7
48           SPLIT      1,START
49           ADVANCE    3000,200
50           TABULATE   5
51           TRANSFER   ,BBBB
52     BBONE SEIZE      6
        XXXX MACRO      6,4
53           ASSIGN     1,6
54           LEAVE      1,7
55           SPLIT      1,START
56           ADVANCE    3000,200
57           TABULATE   4
58           TRANSFER   ,BBBB
59     CCONE SEIZE      5
        XXXX MACRO      5,3
```

```
60              ASSIGN     1,5
61              LEAVE      1,7
62              SPLIT      1,START
63              ADVANCE    3000,200
64              TABULATE   3
65              TRANSFER   ,BBBB
66        DDONE SEIZE      4
           XXXX MACRO      4,2
67              ASSIGN     1,4
68              LEAVE      1,7
69              SPLIT      1,START
70              ADVANCE    3000,200
71              TABULATE   2
72              TRANSFER   ,BBBB
73        XXONE SEIZE      3
           XXXX MACRO      3,1
74              ASSIGN     1,3
75              LEAVE      1,7
76              SPLIT      1,START
77              ADVANCE    3000,200
78              TABULATE   1
79              TRANSFER   ,BBBB
80         BBBB TRANSFER   .500,BRRR,BLLL
       *                              SELECT THE SUBSEQUENT PATH OF FLOW
       *                              ON THE BASIS OF AN EQUAL PROBABILITY
       *                              ASSIGNED TO EACH POSSIBLE PATH .
81         BLLL TRANSFER   ALL,EONE,GONE,6
82         BRRR TRANSFER   ALL,GGONE,EEONE,6
83         EONE SEIZE      8
           YYYY MACRO      8,6
84              ASSIGN     2,8
85              RELEASE    *1
86              ADVANCE    1800,150
87              TABULATE   6
88              TRANSFER   ,CCCC
89         FONE SEIZE      9
           YYYY MACRO      9,7
90              ASSIGN     2,9
91              RELEASE    *1
92              ADVANCE    1800,150
93              TABULATE   7
94              TRANSFER   ,CCCC
95         GONE SEIZE      10
           YYYY MACRO      10,8
96              ASSIGN     2,10
97              RELEASE    *1
98              ADVANCE    1800,150
99              TABULATE   8
100             TRANSFER   ,CCCC
101       GGONE SEIZE      10
           YYYY MACRO      10,8
102             ASSIGN     2,10
103             RELEASE    *1
104             ADVANCE    1800,150
105             TABULATE   8
106             TRANSFER   ,CCCC
107       FFONE SEIZE      9
```

```
          YYYY MACRO      9,7
108            ASSIGN     2,9
109            RELEASE    *1
110            ADVANCE    1800,150
111            TABULATE   7
112            TRANSFER   ,CCCC
113      EEONE SEIZE      8
          YYYY MACRO      8,6
114            ASSIGN     2,8
115            RELEASE    *1
116            ADVANCE    1800,150
117            TABULATE   6
118            TRANSFER   ,CCCC
119       CCCC SEIZE      11
120            RELEASE    *2
121            ADVANCE    600,50       PROCESSING THE MATERIAL AT THIRD STAGE
122            ENTER      2,7
123            RELEASE    11
124            TABULATE   8
125            TRANSFER   BOTH,LFOR,RFOR
126       LFOR SEIZE      12
          FOUR MACRO      12,10
127            ASSIGN     4,12
128            LEAVE      2,7
129            ADVANCE    1050,100
130            TABULATE   10
131            TRANSFER   ,FINAL
132       RFOR SEIZE      13
          FOUR MACRO      13,11
133            ASSIGN     4,13
134            LEAVE      2,7
135            ADVANCE    1050,100
136            TABULATE   11
137            TRANSFER   ,FINAL
     *                                 ACCUMULATION OF FINISHED PRODUCT
138      FINAL ENTER      3,7
139            RELEASE    *4
140            TABULATE   LAST
141        END TERMINATE
142            GENERATE   60000
143            TERMINATE  1
               START      1
               RESET
               START      10
               CLEAR
               END
```

APPENDIX E

Sample Output from Simulation Model 4.

ILLEGIBLE

THE FOLLOWING DOCUMENT (S) IS ILLEGIBLE DUE TO THE PRINTING ON THE ORIGINAL BEING CUT OFF

ILLEGIBLE

FACILITY	AVERAGE UTILIZATION	NUMBER ENTRIES	AVERAGE TIME/TRAN	SEIZING TRANS. NO.	PRE TRAN
PUMP	.834	954	524.756		
3	1.000	192	3125.000	13	
4	1.000	191	3141.361	9	
5	1.000	191	3141.361	10	
6	1.000	192	3125.000	8	
7	1.000	192	3125.000	11	
8	.993	319	1868.118	1	
9	.992	318	1871.842	7	
10	.992	319	1866.006	17	
11	.955	954	600.801		
12	.832	478	1045.027	5	
13	.835	477	1050.842	6	

STORAGE	CAPACITY	AVERAGE CONTENTS	AVERAGE UTILIZATION	ENTRIES	AVERA TIME/TR
1	28	22.143	.790	6699	1983.32
2	14	.000	.000	6678	.04
3	2147483647	3930.248	.000	7266	324545.68

TABLE LAST

ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	S
953	9185.417	81.250	

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER
6500	0	.00	.0	100.0
6600	0	.00	.0	100.0
6700	0	.00	.0	100.0
6800	0	.00	.0	100.0
6900	0	.00	.0	100.0
7000	0	.00	.0	100.0
7100	0	.00	.0	100.0
7200	0	.00	.0	100.0
7300	0	.00	.0	100.0
7400	0	.00	.0	100.0
7500	0	.00	.0	100.0
7600	0	.00	.0	100.0
7700	0	.00	.0	100.0
7800	0	.00	.0	100.0
7900	0	.00	.0	100.0
8000	0	.00	.0	100.0
8100	0	.00	.0	100.0
8200	0	.00	.0	100.0
8300	0	.00	.0	100.0
8400	0	.00	.0	100.0
8500	0	.00	.0	100.0
8600	0	.00	.0	100.0
8700	0	.00	.0	100.0
8800	0	.00	.0	100.0
8900	8	.83	.8	99.1
9000	40	4.19	5.0	94.9
9100	174	18.25	23.2	76.7
9200	298	31.26	54.5	45.4
9300	281	29.48	84.0	15.9
9400	129	13.53	97.5	2.4
9500	22	2.30	99.8	.1
9600	1	.10	100.0	.0

REMAINING FREQUENCIES ARE ALL ZERO

EQUIPMENT CONFIGURATION STUDY
USING DIGITAL SIMULATION

by

SRINIVASAN PRAKASH

B. E. (Mechanical), College of Engineering, Guindy

University of Madras, India, 1967

AN ABSTRACT OF A MASTER'S REPORT

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Industrial Engineering

KANSAS STATE UNIVERSITY

Manhattan, Kansas

1970

Computer simulation is finding a very wide application as a management tool in analyzing and evaluating the behavior of production systems. A feature of simulation is its applicability to a process with equal facility at the many stages of development of the process.

Digital simulation, with GPSS/360 (General Purpose Simulation System /360) as the programming language, has been used to study a multistage batch production process. The process was simulated on IBM 360/50 computer in accordance with the existing configuration of equipment, with a view to introducing logical changes in the model. These changes were aimed at making the system performance better and more uniform.

The study involved the development of four models associated with three configurations. The system performance was studied at different input (pumping) rates and priority rules. The effect of these on the cumulative production, the production rate, the batch production times and the equipment utilization has been studied and presented.

The configuration denoted by 5-3-1-2 has proved to be superior to the others. It exhibits a greater steadiness and a more uniform equipment utilization; it shows also a greater production rate and cumulative production. Another important factor observed is the compactness of GPSS/360 as a simulation language and its ease of applicability to the problems of this nature.