SIMULATION OF A BULK ARRIVAL QUEUEING SYSTEM WITH REFERENCE TO A SOAKING PIT

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CHAPTER 1

INTRODUCTION

Of the primary mineral industries of the nation, processing of iron ore into pig iron and steel is very important. With the rapid changes in technology, new competitive materials, and the rising foreign imports, the steel industry is facing a constant challenge to improve its efficiency. The steel plant processes are both expensive and productive. Thus even a one percent improvement in yield has an impact on its fight for survival. The best way to meet this challenge is through the utilization of all available resources effectively and efficiently. This can only be achieved through a thorough study and understanding of the process coupled with the practical experience gained in the industry.

The purpose of this study is to determine the capacity of the soaking pit in the steel plant given the various parameters. The usual method of easing scheduling problems caused by non-uniformity and uncertainities is to provide more operation units than would be needed. Solving this problem by adding capital equipment such as soaking pits and crane is such an expensive approach that the optimal control and scheduling schemes are well worth investigating.

This chapter includes a general description of an integrated steel plant and its bottlenecks. It also includes a discussion of the soaking pit and crane operations. Chapter 2 is on literature review. Chapter 3 discusses the proposed problem including the assumptions. Chapter 4 is devoted to the simulation model and the computer program. A discussion of the results is made in Chapter 5 and the conclusions are included in Chapter 6.

1-1. DESCRIPTION OF AN INTEGRATED STEEL PLANT

The schematic diagram of a modern integrated steel plant is shown in Fig. 1. The molten pig iron that is produced at the blast furnace plant is either brought in ladle cars and poured into a mixer, or sent to the cast house where it is cast into pigs. A mixer is a large refractory-lined cylindrical vessel, mounted horizontally on rollers or trunnions so that the metal can be poured from a spout in its centre by merely tilting the mixer.

The chief function of the mixer is to furnish storage space for the pig iron, so as to make the steel making process unaffected by the time interval between casts. Thus a minor breakdown or a delay either at the blast furnace or at the steel making furnace will not affect the other. Irregularities do occur in the blast furnace operation, and sometimes it takes a long time to discover the defect and rectify it. Another advantage is that the composition of metal can be controlled within narrow limits, which is hard to achieve at the blast furnace, inspite of great advances in its operation. The mixer also keeps the metal molten for an indefinite period of time. The conservation of heat effected by the mixer is but one example of the heat economy effected in an integrated iron and steel plant. At every stage in the making and shaping of steel, the material must be maintained at a high temperature to perform a required operation.

Steel is produced in a steel making furnace using either the molten iron from the mixer or scrap or both. It is then tapped into ladles. The ladle--cup shaped--is a large refractory-lined vessel equipped with trunnions on either side by which a crane supports it. The ladle is transported by a crane to the pouring platform and teemed into cast iron molds waiting there on a 'drag' of railroad cars. The drag of molds is held for a time specified

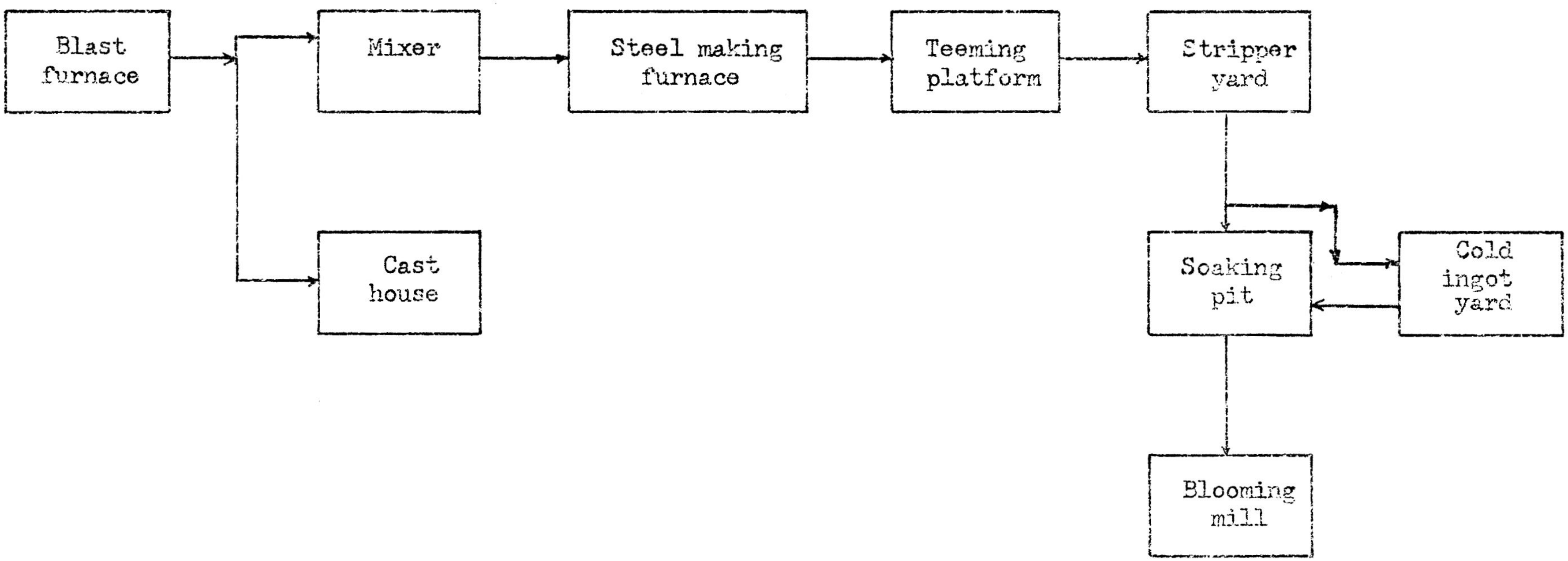

Fig. 1. Schematic diagram of a steel plant

by the metallurgical department. They are then brought to the stripper yard where the molds are stripped from the ingots by the stripper cranes.

Producing an ingot is an important operation in the steel industry. Even well made steel may be completely ruined by the poor ingot practice; of course a poorly made steel can not be made into good ingots with the best ingot practice.

After the molds are stripped from the ingots, the ingots continue their journey to the soaking pit and are charged into the pit by an overhead travelling crane. After attaining the required temperature, the ingot is removed by the same crane to the 'ingot chariot', usually a rail mounted car, which deposits it on the end of the 'live roller table'. These live rollers transport the ingot to the blooming mill or slabbing mill.

This study is centered around the soaking pit.

1-2. BOTTLENECKS IN STEEL MAKING

The processing times in the steel making furnaces are difficult to predict accurately. This is true with all the operations in the steel plant. The number of ingots produced per heat may also vary from one cycle to another. Sometimes the chemical analysis might show that the steel produced can not be used for that specific purpose. It has to be scrapped. Further breakdowns do occur with the equipment because of heavy use. These are very difficult to predict in time, location and duration. The goal of attaining a smooth flow will be accentuated by operating different departments for different hours a day.

There is also a tendency to concentrate the efforts on the outputs of the blast furnace, steel melting shops and rolling mills, neglecting the other allied aspects of the whole complex. If proper attention is not given in the design and operation of the soaking pit, it will become a serious bottleneck. The railroad track in the ingot processing area can become a bottleneck too, at high operating levels or when the existing facilities are expanded. The operating levels at which this bottleneck occurs, depend upon the location of the steel making shops, the railroad track layout, and the number of engines and railroad cars available [18].

1-3. THE SOAKING PIT

For an ingot to be properly fabricated by either forging or rolling, the metal must be at the proper temperature and also the temperature of the mass must be uniform. As the ingot is stripped from the mold, it possesses neither of these requirements; so it must be given a preliminary conditioning treatment before it can be worked. When the ingot is removed from the mold, the outside is cooler than the interior--in fact, big-end-down ingots are often stripped before they are entirely solid, particularly when made of the semi-oxidized class of steel. This unevenness of temperature of the ingot must be removed by soaking the ingot in a pit furnace, called a 'soaking pit'. This is done until the ingot is solid and at a uniform and desired temperature.

The soaking pits used today are of three different designs--the reversing regenerative type of pit, the one way fired recuperative pit and the circular non-regenerative pit. A heavy, brick-lined steel cover is provided for the upper opening of the pit. The cover is equipped with wheels which run on a track laid on each side of the pit. When the charging is completed, the fuel flow rate is maintained at a preset maximum until the furnace temperature reaches the set value. At this point the temperature controller regulates the fuel flow, to keep the furnace temperature fixed at the set point, until the ingots are drawn from the pit. The fuel is usually cut off when charging or drawing ingots. The ingots are placed upright in the pit and spaced in such a way that all the sides are heated evenly and yet the flames do not strike them.

The correct temperature for rolling or forging will depend upon the class of steel being treated. Rolling temperatures of 2150°F to 2450°F have been used in practice [5]. The temperature at which rolling is commenced should be adequate enough to allow the deformation of the material without need for excess power. Also the material should be at the desired temperature at the completion of hot work, since this temperature will affect the properties of the steel in the 'as rolled' condition [2].

The higher the temperature at which the metal is rolled, the easier it will deform and the lesser the power required. On the other hand, it should not be heated enough to begin to melt. If the temperature is excessive, the steel may also be burnt. When the ingots are rolled at high temperatures, they are likely to crack unless very carefully handled. The interior of the bloom or billet will be porous also, causing a serious defect called a 'coky centre'. In the other case, if it is underheated the power required to cause the deformation increases, which may in turn necessitate the reduction of rolling speeds. Further, it is difficult to obtain the desired section. If the ingot is heated unevenly, it will cause uneven reductions in area on subsequent rolling. It will often lead to the formation of mechanical defects.

1-4. A DISCUSSION OF THE SOAKING PIT OPERATION

The soaking time of an ingot mainly depends on its quality and its track time. Track time is the time interval between the completion of teeming and charging of the ingot into the soaking pit. Immediately after the teeming of an ingot is completed, the liquid interior which is surrounded by a solid skin or chill, will be at a temperature of approximately 2700°F, depending on the composition of the steel. For subsequent rolling of this ingot, it must be at a temperature of approximately 2200°F. Theoretically, it should be possible to strip the ingot from the mold and transfer it immediately to an unfired soaking pit; then the heat from the interior can diffuse giving a uniform temperature of the desired value throughout the ingot. But Brancker et al. [4] noted, that although the steel at tapping contains 5 therms/ton* more heat than is required for rolling, no less than 10-20 therms have to be supplied in the soaking pits. It should also be noted, that in order to restore the heat lost during one hour of cooling, two hours of heating in the soaking pit is required [2].

As is noted earlier, the only way to reduce heating time in the soaking pit is to maintain a low track time and charge the ingots immediately after they arrive. At the other end if casts are charged in rapid succession into the soakers, later there will be a surplus of ready-to-roll casts: they increase their occupancy of the soakers and again the throughput is decreased. Conversely, if there is a dearth of casts to charge at any time, this may lead later to a dearth of ready-to-roll casts and to idle time of the mill. This will again decrease the throughput of the whole system.

The soaking pits and the rolling mills are usually designed to take the entire output of the various melting furnaces without overloading them. When there is a breakdown either at the mill or at the soakers, more casts are delivered to the soakers than they can accomodate. Such casts will go cold and must be reintroduced to the soakers at a later time. If different

*1 Therm = 100,000 BTU

departments are working in different shifts, the casts produced during a particular time may be classified as cold.

Thus a strategy for introducing cold stock to the soakers is required. If the process times for steel making, tapping, stripping, transporting and rolling are deterministic, a schedule can be drawn; but the high variability of the process times makes such a planning very difficult. An understanding of the implications of the different decisions will help a lot in arriving at a correct course of action.

Because of the vast difference in heating times for cold and hot material, it is necessary to forecast the hot arrivals to determine if a cold cast should be charged to the soakers. This major decision depends on the need for the hot supply to be augmented in the future and on the ability of soakers to accomodate both the cold casts and the following hot casts.

Errors in the forecasts necessary in making decisions to charge cold ingots can lead to a bad decision; once such a decision is made, it is irrevocable. If the hot steel arriving after a cold charge departs too much from the expected pattern, then either the capacity of the soakers is exceeded or the mill runs out of ready-to-roll steel. This situation can only be rectified by producing low quality steel.

It will pay to allow a cast arriving later with a short track time before an earlier cast with a long track time using LIFO (last in first out). This will appreciably reduce the heating time for the present cast. The additional delay to the earlier cast will increase its soaking time, but in the face of an oncoming shortage of ready-to-roll steel, the extra occupancy of the soakers may not be disadvantageous. This may still fill another later gap in ready-to-roll steel. Usually in a cast, the first ingot teemed is also the first ingot to be stripped and charged into the soakers.

1-5. CRANE

An overhead travelling crane handles the charging of ingots into the soaking pit and removes them from the pit, after being heated to the required specification. The usefulness of bridge cranes is derived by their lifting strength and overhead accessibility which makes them capable of handling heavy, unwieldy loads which are not accessible to the surface locomoted material handling systems.

The three members of a crane are bridge, trolley and hoist. The bridge is supported on railroad type tracks, located at the top of, and on opposite sides of the building. The bridge moves in a direction perpendicular to its length on the tracks at either end. The crane's movement is necessarily restricted, then, to rectangular bays, having one dimension narrow enough to be spanned by the bridge without excessive physical stress. A trolley containing a hoist mechanism traverses from one end of the beam to the other, in order that with the combined beam movement, the hoist can be centered over any spot of the bay. The hoist is usually motor driven having tongs at the lower end for holding the ingot to be transported.

1-6. CRANE OPERATION

It is assumed that the hoist can be worked to the correct position in the time it takes to move the bridge and the trolley. The service time of the crane is the sum of a constant time and a variable time. The latter depends upon the speed of the crane and the length of the travel. So the service time of the crane can be calculated if the exact position of the ingot and the empty cell are known. Here the bridge and trolley speeds are considered. The maximum time of travel is used in determining the crane service time.

To simplify the calculations, a distribution of the service times can be generated for the random occurrance of an empty cell and a travel distance. When the crane is servicing an ingot, the service time can be determined from the distribution.

A policy decision must be made regarding the method of filling in the empty cells and the use of the crane. If an approximately constant service time has to be achieved the ingot nearer to the pit should be placed in a cell farther away from the train. On the other hand if a shortage of heated ingots is anticipated or the crane has to draw a heated ingot, the ingot should be charged into the nearest available cell.

The same crane is used to charge arriving ingots and cold ingots and draw heated ingots. Which should have the preference must be specified. If a heated ingot is not picked up by the crane, the immediate production of the rolling mill is effected. Also, in the extreme case when the soaking pit is full, a hot ingot can not be charged. If the hot ingots are not charged, future production is affected. It is possible to use a policy of giving preference to one of the three according to the availability of number of empty cells at that moment.

CHAPTER 2

LITERATURE REVIEW

Mellor and Tocher [15] developed a production game to improve the methods of controlling the production and movement of casts of steel from the melting shops to the rolling mills. The main concern was to develop a scheduling system which will ensure that the idle time at the mills is minimum; also to see that the casts of steel of the correct types to meet an order book were supplied. The model fed information to and took instructions from the scheduler.

Blattner [3] developed a simulation model to determine the soaking pit capacities and operating characteristics at peak volume and product mix for different combinations of proposed facilities and equipment. It was found that the number of pits required to take care of the increased production was less than that calculated using the conventional rule of thumb method. Kung et al. [12] simulated an ingot processing area. The simulation includes all the processess that have strong interactions. The model was validated by comparing computer results with the actual plant performence.

Raymond [18] pointed out the 'law of diminishing returns', when more soaking pits are added. As more soaking pits are added, the throughput of the soaking pit-slabbing mill complex doesn't increase proportionately. This increase is a function of rolling speed, product mix, and rolling mill delays. The increase in the rolling rate of the primary rolling mill has a favourable effect on the throughput; but when the throughput is already limited by the soaking pits, the favourable effect is small. Finally the railroad track in the ingot processing area can become a bottleneck at high operating levels.

The operating level at which this bottleneck occurs is dependent on the location of the steel melting shops, the railroad track layout, the number of engines and the railroad cars available.

The control of ingot traffic operation was studied by Thomas et al. [21]. Three points were made:

1. Sensitivity of the slabbing mill output with a given number of soaking pits to the efficiency of traffic planning.
2. Recognition that, although a short average track time was desirable, track time could and should be manipulated for other ends.
3. Demonstration of the importance of ease of communication to the efficient control of a particular plant system.

The time an ingot occupies the pit is the sum of

1. The time the pit is empty and waiting to be charged
2. The time it takes to bring the charge to a suitable state for rolling, measured from the start of charging and
3. The time that then elapses before the charge is rolled.

Decreasing the track time decreases only the second component. But to have a maximum throughput, the sum of the three must be minimized. To this end traffic should be controlled. The effective control of traffic increases the output and achieves smoother working of a complex sector of an integrated steel works.

Kung et al. [11] developed a mathematical model to describe the cooling of steel ingots and their subsequent heating in the soaking pits. It consists of the basic two dimensional partial differential equation of transient heat conduction and equations describing boundary conditions. The part of the model which covers the cooling of ingots between teeming and charging into the soaking pits was tested against data on mold and ingot surface temperatures. The part on ingot heating in the soaking pits was tested against data on fuel flow and pit wall temperatures. They indicate that the basic form of the model is satisfactory.

A one dimensional theoretical model for soaking pit times was developed by Corlis et al. [7]. The effect of optimal track time, short track time and long track time was investigated. An optimal track time is defined as a combination of time with or without the mold, which enable the best rolling temperature conditions to be met with minimum pit time. Ingots charged with a short track time carry the danger of maintained liquid cores and hence segregation faults. Longer soaking times are required to allow the cores to solidify. If the track times were lengthened by holding the ingots in air for a short period, the soaking time before rolling would be shortened considerably. Ingots charged with the optimal track time produce the most rollable ingots with the minimum pit time. Excess track times destroy the advantage of hot cores and multiply the time required in the soaking pit. The relation between the track time and the soaking time can be represented by a 'U' shaped curve. Practices such as 'bottling' the pit--charging the ingots but leaving the fuel off, when short track times are achieved--are not as efficient timewise as holding the ingots in air for an extra period before charging.

Sharma [19] derived an analytic solution to the queueing model with the bulk arrival at the soaking pit. It was assumed that the interarrival time was independently distributed. The arrival rate at the service station has a poisson distribution. All the ingots are served by a number of service stations--heating cells. The service time (soaking time) of the ingots in the soaking pit is a random variable, independently distributed. The inter-arrival times and service times are statistically independent. The groups receive service in order of their arrival. The order of customers in a particular group is immaterial.

CHAPTER 3

THE PROPOSED PROBLEM

The problem is to determine the soaking pit capacity and operating characteristics, given the ingot heating time formula, input to the system and crane characteristics. For the arriving ingots, the distribution of interarrival times and the number of ingots on a train are given. No cold ingots are supplied from outside the plant; cold ingots may be created because of the unavailability of the crane or the soaking pit. They are charged in the course of the soaking pit operation. A secondary problem is to investigate the effect of the various parameters on the output and gain an understanding of the operation of the soaking pit. The following characteristics of the system are also to be observed.

1. The effect of the decisions--charging cold ingots or arriving ingots, or drawing heated ingots.
2. The distribution of time between departures of ingots from the system.
3. Output distribution of the heated ingots per hour.
4. Distribution of the number of empty cells.
5. Distribution of the excess soaking time--same as the waiting time for the soaked ingots.
6. Average utilization of the pit.
7. Maximum utilization of the pit.
8. Probability that the pit is full.
9. The distribution of the waiting time for the arriving ingots.
10. Distribution of the number of ingots arriving in a batch.

3-1. THE PHYSICAL SYSTEM

No allowance is made for failure, periodic servicing, shifts or any other interruptions in the operation of these equipment, Fig. 2. The number of parallel tracks for the trains varies with the model. The distances of the cold ingot yard, arriving ingots, and ingot chariot from the soaking pit are known. The capacity and dimensions of the soaking pit are known. The capacity of the soaking pit is specified as the number of cells in the soaking pit. Each cell can heat only one ingot at a time. The ingot for which the cell is allotted has complete control over the cell until the heating phase is completed and the crane is available for drawing the heated ingots. The preemption of the ingot is not allowed, once it occupies the cell. The crane performs three functions--charges arriving ingots, charges cold ingots and draws soaked ingots. The heating time of an arriving ingot, THEAT, is calculated from the heating time formula shown below:

$$\text{THEAT} = \begin{cases} \text{A1}\ (\text{X}-\text{TT1})^2 + \text{PT1} & 0 \leq \text{X} \leq \text{TT2} \\ \text{A1}\ (\text{TT2}-\text{TT1})^2 + \text{PT1} + \text{A2}\ (\text{X}-\text{TT2}), \quad \text{X} > \text{TT2}, & \text{THEAT} \leq 8 \\ 8, & \text{THEAT} > 8 \end{cases}$$

where A1, PT1, TT1, TT2 and A2 are all constants read into the program initially and X is the track time of the ingot. For a cold ingot, the heating time varies between 8 hours and 10 hours. The heating time curve shown in the Fig. 3 represents the relation between track time and heating time for an arriving ingot.

3-2. SIMULATION MODEL AS A QUEUEING PROCESS

The basic structure of most of the queueing processes consists of the following: units requiring service are generated over time by an input

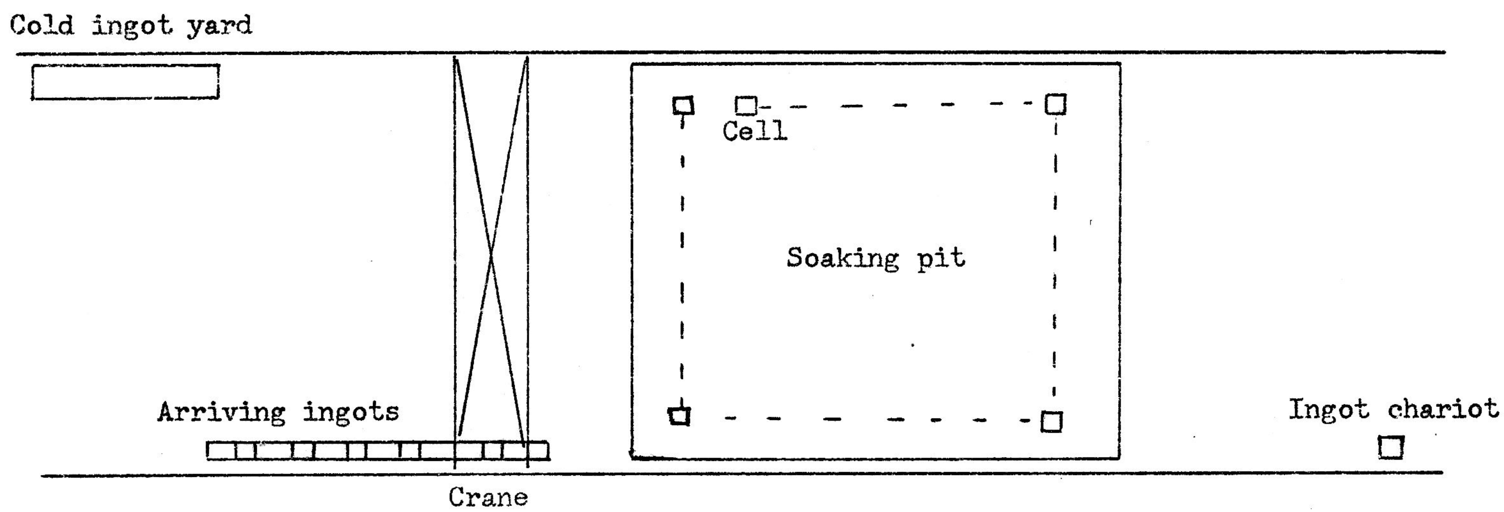

Fig. 2. The physical system

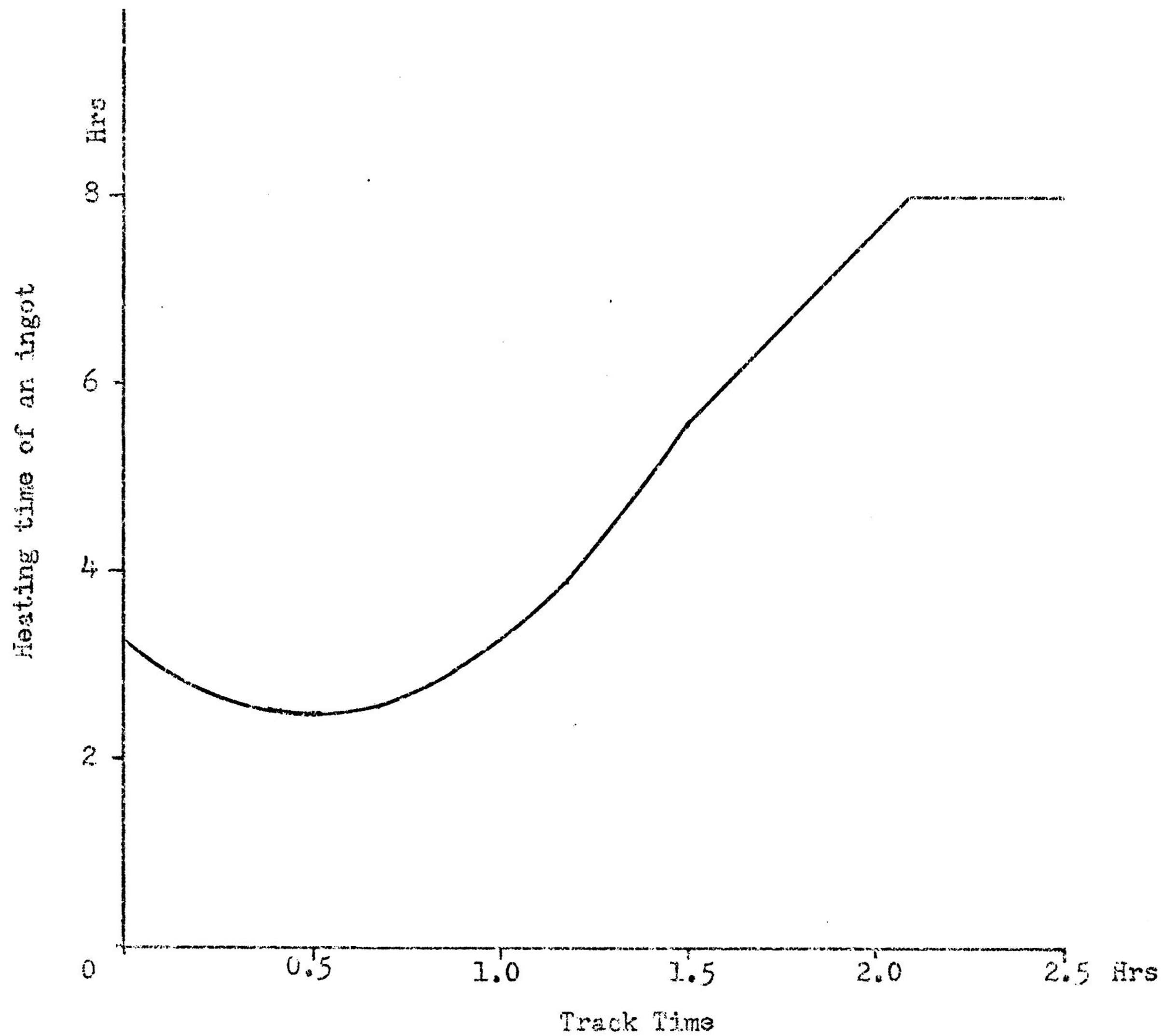

Fig. 3. The heating time curve

source. These units enter the system and join a queue. At a certain time, a unit waiting in the queue, is selected for service by some rules referred to as queue discipline. The required service is then performed in the service station, after which the unit leaves the system as an output [1] Fig. 4. As indicated above the elements of the queueing process are:

Input: Ingots as arrivals have the following sub-elements

1. Arrival source--Infinite: Ingots are produced continuously throughout the year and arrive at the soaking pit for being heated.
2. Arrival pattern--Batch: The ingots arrive in groups on a train. It is assumed that the batch size follows a normal distribution.
3. Inter-arrival distribution: Erlang 4 is assumed in most of the runs. Erlang 1, Erlang 8, and constant inter-arrival times are also used.
4. Arrival behavior: Impatient--in model 1, model 2, model 4 and model 6.

   Patient--in model 3 and model 5.
5. Cold ingots: These are created in some models. The queue is unrestricted. The size of the queue depends upon the operating system.

Crane: It services arriving ingots, cold ingots and soaked ingots.

arriving ingots:

Queue discipline--depends on the model under consideration: LIFO, FIFO, MIXED.

Queue size--depends on the model: limited or unlimited.

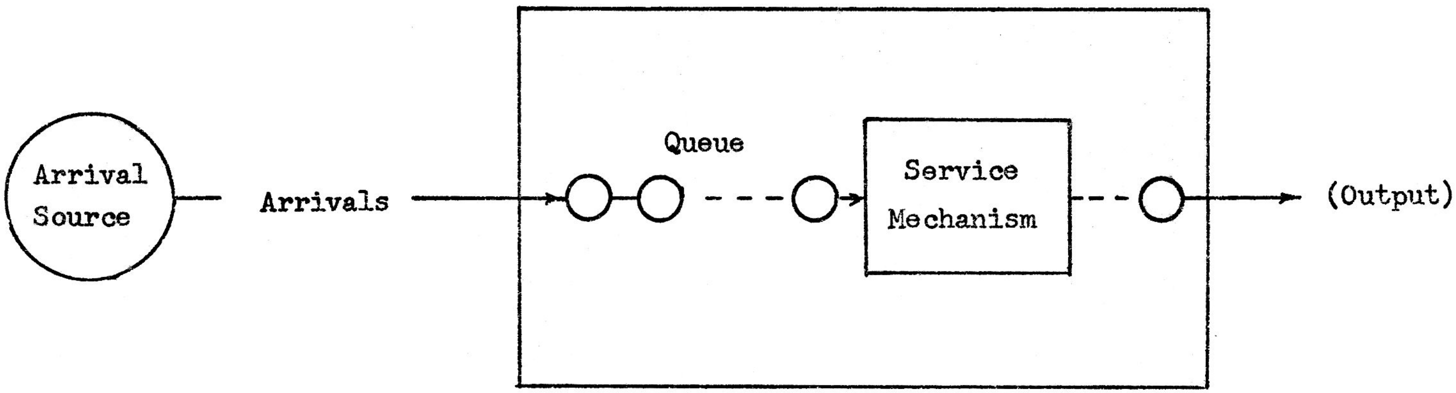

Fig. 4. The process from the queueing point of view

soaked ingots:

Queue discipline--FIFO.

Queue size--restricted. Equal to the soaking pit capacity.

service pattern--single.

service mechanism--single service station.

service time--depends on the speed of the crane and the travel distance in the two directions.

Heating cell:

Queue discipline --FIFO.

Queue size --zero.

service pattern --single.

service mechanism--parallel.

service time --it is determined from the heating time curve. It is a function of the track time.

The cell which is emptied first will service the charging ingot first. A cell is defined to consist of one server and a zero queue. The server is a single cell that is constantly available to the input stream of ingots, when the crane is available.

3-3. THE DECISION RULES

Four types of decisions are made:

1. Charging arriving ingots.
2. Charging cold ingots.
3. Drawing soaked ingots.
4. Banking of ingots.

The first three effect the crane operation. They are directly related to the number of empty cells. The ratio of the number of empty cells to the total number of cells is named as priority ratio. If this ratio is less than FRAC 2, the soaked ingots are drawn from the pit first. If this ratio lies between FRAC 2 and FRAC 1, preference will be given to the charging of arriving ingots. If it is greater than FRAC 1, cold ingots will be charged first.

The decision to bank the ingots varies from model to model. In Model 3 and Model 5, cold ingots are not created. In the other models it is decided upon by the maximum length of time the train can stay at the soaking pit or the maximum number of trains that can stay near the soaking pit.

3-4. ASSUMPTIONS

1. No allowance is made for failure, shifts, periodic servicing or any other interruptions in the operation of the equipment.
2. A 'U' shaped heating curve is assumed. This is based on the study made by Corlis [7]. The data assumed is for a hypothetical steel plant. It incorporates the concept of optimal track time, short track time and long track time. A straight line relationship is assumed after a certain track time. The heating time is less than that of a cold ingot.
3. For a cold ingot, the heating time is assumed to be between 8 hours and 10 hours. Uniform distribution is assumed.
4. Instead of measuring an absolute transit time of ingots from teeming to the arrival at the soaking pit, a relative transit time is used in the problem. This transit time has a normal variation about the optimal time. The trains can arrive at the most 0.5 hours ahead of the optimal time or 1.0 hour after the optimal time. This variation is changed in a few runs to see the effect of it on the output.

5. The number of ingots on a train is assumed to have a normal distribution.
6. Inter-arrival times for trains is assumed to have an Erlang 4 distribution. It is based on the fact that the variation in the interarrival times is less in actual practice.
7. The crane service time is assumed to depend on the speed of the crane and the travel distance. The vertical motion of the hoist is not considered. All the other variations are accounted in the constant time for the crane.
8. The exact position of the cell for charging an ingot or drawing a soaked ingot is not considered. It is assumed to be randomly situated within the soaking pit.
9. The location of the crane after servicing the ingot is neglected.
10. No crane service time is involved in placing an ingot in the cold ingot yard. It is assumed that there is another crane at the cold ingot yard.
11. The soaked ingots are removed from the pit immediately after the crane is available. It is not dependent on the rolling requirements.
12. It is assumed that the crane operator has the full information on the number of empty cells in the soaking pit at any moment.
13. Each cell is assumed to have an independent heat control device.
14. No over charging of the pit is allowed.
15. In collecting statistics on the time between departures of ingots from the system, the first value is omitted. At the beginning, since all of the cells are empty, the first soaked ingot will

depart from the system after a long time. This first value increases the standard deviation of the time between departures by 50 percent.

16. No cold ingots are supplied from outside the steel plant. But they may be created during the operation of the soaking pit.

17. At the start of the simulation, there are no cold ingots in the system; all the cells are empty and a train of arriving ingots are waiting to be charged; the crane is idle.

CHAPTER 4

DESIGN OF THE SIMULATION MODEL

This type of problem is known mathematically as a queueing model. Since random or stochastic irregularities are being dealt with, a probabilistic as opposed to a deterministic model is required. While analytic mathematical techniques have been developed to solve simpler queueing models, in the more complex case faced here, it is necessary to resort to simulation techniques in order to predict the behaviour of the system. If the arrival distribution, service time or service discipline are changed, a new solution has to be derived analytically. Further, the distributions have to be approximated to some known, standard distributions. Hence the mathematical model approach, while being beautifully clear, may give an exact solution to a problem which is approximate.

Simulation is the duplication of environment by a model, such that changes can be made at will to test particular outcomes of these specifications on either the immediate problem part or on the total effect. The problem of, why system simulation, is discussed clearly by Teichroew and Lubin [20]. The purposes for which the simulation studies can be put to use are discussed by Mize and Cox [16]. It should be remembered, that simulation is no alternative, to the scientist spending time and patience, in knowing what is happening in the real life. But a simulation model forces on the scientist a detailed understanding of the quantitative process involved in the situation he is observing.

The first step in a computer simulation is to develop a logical model of the system preparatory to the writing of the computer program. This model is of necessity an abstraction of a real life situation involving men, materials, equipment and processes. It should be remembered that simulating every plant detail would require excessive computer memory space and execution time, and insignificant details would obscure the significant issues. So only those essentials which are significant to the study are retained. In this process of abstraction, all available resources including formalised basic standard relationships between variables, operating experience, and intuition are utilized.

The simulation model consists of a set of logical statements, expressed in the form of a computer program, that describes the routing and sequencing of ingots through the ingot processing area. These interactions and sequence of events occur at discrete times; then the position, quantity or the status of the material or the status of the processing equipment changes.

Some events occur exogenously; that is, without regard to the condition of the operation under study. Others occur endogenously; that is, they are caused by the internal working of the operation. An 'arrival of a train--ARIVL' is exogenous, since the train arrival is not affected by operations in the simulation area. A 'heating of an ingot--EHEAT' is endogenous, since its timing depends upon the internal workings of the simulated operation.

In addition to the program, two types of data must be supplied to the computer: a description of the arrival times of the ingots and the numerical values of all the parameters used in the program to describe the physical characteristics and process times.

4-1. COMPUTER PROGRAM

The logical model and data compose the model of the simulated plant area. The task remains however, to convert these into a computer program, that can be used to generate outputs from the model. To simplify the programming, a simulation programming language was sought, that would require less programming work and is flexible enough to be used on any machine.

A chronological recording of future events is called 'timekeeping'. Timekeeping will be thought of as two functions; that of advancing time or up-dating the time status of the entities and that of storing or listing events in the computer. The timing problem in digital simulation models arises from the fact, that while the components of a real system function simultaneously, the components of a simulated system function sequentially, since a digital computer executes its instructions one at a time [6].

Two basic mechanisms are available to represent the flow of time in a simulated model: the uniform increment method and the variable increment or next event method. In the uniform increment method, the program lets the simulation run for an increment of time and then up-dates the system. The variable increment method involves the portrayal of a system through time by examining the system at each event instant.

Lave [13] discussed the two methods of timekeeping and compared them on the basis of precision and accuracy, runtime and computer storage required. Generally the next event method should be preferred to that of uniform increment method. A uniform increment method is preferred in the following two situations: when the next event model takes a long time to run on a digital computer and when the inaccuracies built into the model will not destroy its usefulness [18, pp. 118-125].

A next event type of simulation language, GASP--General Activity Simulation Program--is selected for use in this problem [17]. There are several features, which make it attractive as a simulation language. It consists of

22 subprograms which can be used to accomplish certain operations common to many simulation studies. A system is described by the entities (elements). These entities are described by attributes. These are acted upon by other elements through events. An event is an occurance, a taking place or a possibility of taking place of a change in the state of a system. Events take place at specific points in time as determined by the system to be simulated. The entities are in turn associated with the files. Thus a system is described in terms of entities, attributes, events and files.

4-2. PROGRAM DESCRIPTION

Events occuring in the simulation:

Event Code	Event Type	
1	ARIVL :	Arrival of ingots at the soaking pit.
2	EHEAT :	The start of the required heating of an ingot.
3	ECRANE:	Start of the crane service.
4	HREP :	A short intervel, HRS, to gather statistics.
5	REPORT:	Print out of all the statistics in the intervel, DELTA.
6	COMPL :	Completion of the heating of an ingot.
7	INST :	An event to initialize the statistics.

Four files are used in the simulation.

FILE 1* : Event file.

Attribute 1--Scheduled time of event.

Attribute 2--Event code.

Attribute 3-- (a) the time at which the ingot was charged into the cell--for event code 6.

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*Multiple attributes are stored in the same row of NSET.

(b) Time ingot enters the system--for other event codes.

Attribute 4-- (a) Number of ingots on a train--for event code 1.

(b) A variable L1, which specifies whether a cold or an arriving ingot should be heated--event code 2.

(c) Heating time of an ingot--event code 6.

FILE 2 : Arriving ingots to be charged into the cells.

Attribute 1--Distance of ingot from the pit.

Attribute 3--Time ingot enters the system.

Attribute 2 and 4--Not used.

FILE 3 : Heated ingots waiting for the crane.

Attribute 1--Time ingot was ready after being heated.

Attribute 3--Time ingot entered the cell.

Attributes 2 and 4--Not used.

FILE 4 : Empty cells.

Attribute 1--Time the cell became empty.

Attributes 2, 3 and 4--Not used.

The computer program for the simulation is shown in Appendix E. The 17 GASP routines are not included. It contains one main program, one event selection sub-routine and the event subroutines. The function of each of the subroutines can be summarized as follows:

1. Main Program: All the initial values for the physical system are read into the program. All other values of the non-GASP variables are initialized. The crane is idle at the start of the run. It calls subroutine GASP. The initial number of empty cells, the arrival of train, and the report intervels are read into the program. The simulation is terminated at the end of the specified time, Fig. 32.

2. Subroutine Events: It calls the appropriate event. Event code '1' signifies an arrival of ingots at the soaking pit, code '2' for the start of the required heating of an ingot, code '3' for the start of the crane service, code '4' to gather statistics in a short interval, HRS, code '5' for the print out of all the statistics in the interval, DELTA, code '6' for the completion of the heating of an ingot and code '7' for the initialization of all the statistics at the specified time, Fig. 33 and 34.
3. Subroutine ARIVL: It varies from model to model. They are described below.

Model 1: When an ARIVL event occurs, it checks for arriving ingots waiting to be charged. If there are any, they are sent to cold ingot yard. Then the arriving ingots are placed in the waiting line for the crane. The distance from the pit and the time at which it entered the system are noted. The next ARIVL is scheduled by generating the interarrival time from the given distribution. The number of ingots on the train is generated from the function RNORML. If the crane is idle it is called for servicing the arriving ingots. A return to GASP is made through EVENTS, Fig. 35.

Model 2: When an arrival event occurs, it checks for arriving ingots waiting for the crane. If there are none, the arriving ingots are placed in the waiting line to be serviced by the crane. The distance from the pit and the time at which it entered the system are noted. If there are ingots waiting, the following procedure is followed: the present train is placed at the front of the soaking pit, if there is space for it. Otherwise it checks for space at the back of the existing train and files the ingots. More than three trains can't stay on the track. If no space is available, the train is sent to the cold ingot yard. The scheduling of the next ARIVL and the remaining procedure is the same as in Model 1, Fig. 36.

Model 3 and Model 5: In the two models, the number of track for the trains is not restricted. The ingots are filed on the basis of the time at which they enter the system. The queue discipline is LIFO--last in first out. The ingots arriving on a train are placed in the waiting line for the crane, after noting the time at which they entered the system and the distances from the pit. No cold ingots are created. The scheduling of the next ARIVL and the remaining procedure is the same as in Model 1, Fig. 37.

Model 4 and Model 6: It is similar to Model 3 except in the assumption of the number of tracks at the front of the soaking pit. If a train stays for more than TQ hours, it will be sent to the cold ingot yard, Fig. 38.

4. Subroutine ECRANE: First the type of service the crane should perform is determined--to charge an arriving ingot or a cold ingot, or to draw a soaked ingot.

The crane will try to service an arriving ingot if one is available. If there are arriving ingots, empty cells are checked. If there is an empty cell, an arriving ingot is removed from the waiting line. The crane service time is determined and the crane is scheduled for the next operation. The start of heating of an ingot is scheduled at the end of the crane service time. The type of service for the next crane operation is determined. If an arriving ingot or an empty cell is not available, it checks for a soaked ingot waiting for the crane. If there is a soaked ingot it will follow that routine; otherwise the crane will be idle.

When charging cold ingots, a check is made for cold ingots. If a cold ingot is not available, it will try to charge an arriving ingot. If there is a cold ingot it will check for an empty cell. If it is available, the crane service time is calculated and the crane is scheduled for the next operation. The start of heating of an ingot is scheduled at the end of the crane operation. The type of service for the next crane operation is determined. If an empty cell is not available, a check is made for a soaked ingot and the crane will follow that routine.

When the crane has to draw a soaked ingot, it will first verify whether soaked ingots are available in the system. If one is available, it will pick up the soaked ingot. Crane service time is calculated and the next crane operation is scheduled. An empty cell is created. The type of service for the next crane operation is determined. If a soaked ingot is not available, it will try to charge an arriving ingot.

A return to GASP is made through EVENTS, Fig. 39.

5. Subroutine EHEAT: It is called when an ingot is to be heated to the required temperature. An empty cell is removed from the file. The type of ingot--cold or arriving--is determined. The appropriate heating time is calculated from the heating time formula. A COMPL event is scheduled at the end of the required heating. A

return to GASP is made through EVENTS, Fig. 40.

6. Subroutine COMPL: The soaked ingot is placed in the waiting line for the crane. If the crane is idle the type of crane operation is determined and the subroutine ECRANE is called. A return to GASP is made through EVENTS, Fig. 41.

7. Subroutine HREP: It will generate the next report interval, HRS, to collect data on the system. A return to GASP is made through EVENTS, Fig. 42.

8. Subroutine REPORT: It will print out all the statistics collected in the interval DELTA. A return to GASP is made through EVENTS, Fig. 43.

9. Subroutine INST: It initialises all the statistics when the steady state is reached. It schedules REPORT event. A return to GASP is made through EVENTS, Fig. 44.

CHAPTER 5

DISCUSSION OF THE RESULTS

The discussion of the results is divided into five sections. First the determination of the steady state is discussed. The effect of the priority ratio and how the time between departures of ingots from the system and the output of soaked ingots vary with the changes in the parameters are discussed. General observations are made in the final section. A summary of the simulation output for different runs is shown in Appendix D. In referring, Model 4/(22) means, the type of model is 4 and the run number is 22.

5.1. STEADY STATE

A simulation model requires several cycles to attain a steady state. So the two important tasks to be accomplished in the simulation of the stachastic process under consideration are the following: the determination of the point of convergence to the steady state and the determination of the period through which the experiment will be performed.

To record the performance of the system, two alternatives are available: ignoring data generated in some initial period or choosing starting conditions that approximate the steady state conditions. Since a reasonably accurate starting conditions for all variables can't be specified, a combination of the above two are utilized [16]. The starting conditions, as in other simulation models, are assumed to be simply, idle and empty. With these starting conditions, the simulation is allowed to proceed for some time. The final conditions of the transient state are assumed to be the initial conditions for the experiment. The question is to determine the time for which the simulation model has to be run to obtain the initial conditions.

Analytical techniques are not available to determine the steady state. The best way is to determine this by experimenting with the model under consideration. The criteria that can be used in the determination of the steady state are the number of empty cells, the utilization of the crane, the output of soaked ingots per hour and the number of cold ingots in the cold ingot yard. The first criteria is not utilized because of large variability and small population. Fig. 5 and 6 show the other three criteria plotted with 7 ingots per train arriving at half an hour interval. The FRAC 1, for charging cold ingots is 0.6. From this it can be seen that the output of ingots per hour and the crane utilization reach a steady state at 30 hours of simulation.

The next question is the determination of the period for which the experiment has to be performed--length of the simulation run. The criteria of cold ingots in the cold ingot yard can be used here. The system can be considered to be in equilibrium when the input (number of arriving ingots per hour) to the system is equal to the output (number of soaked ingots per hour) of the system. This can be achieved only when the number of cold ingots in the system becomes steady. As shown in Fig. 6, the number of cold ingots in the system are increasing for model 4/(37). They are not increasing in the model 6/(35). To observe the output of ingots per hour and the crane utilization in one hour, it is sufficient to run the model for 100 hours after reaching the steady state, Fig. 7 and 9. But to observe the cold ingots in the system, it should be run for 200 hours, Fig. 8 and 10. So it is decided that the statistics should be initialised at 30 hours and the simulation should be terminated at 230 hours.

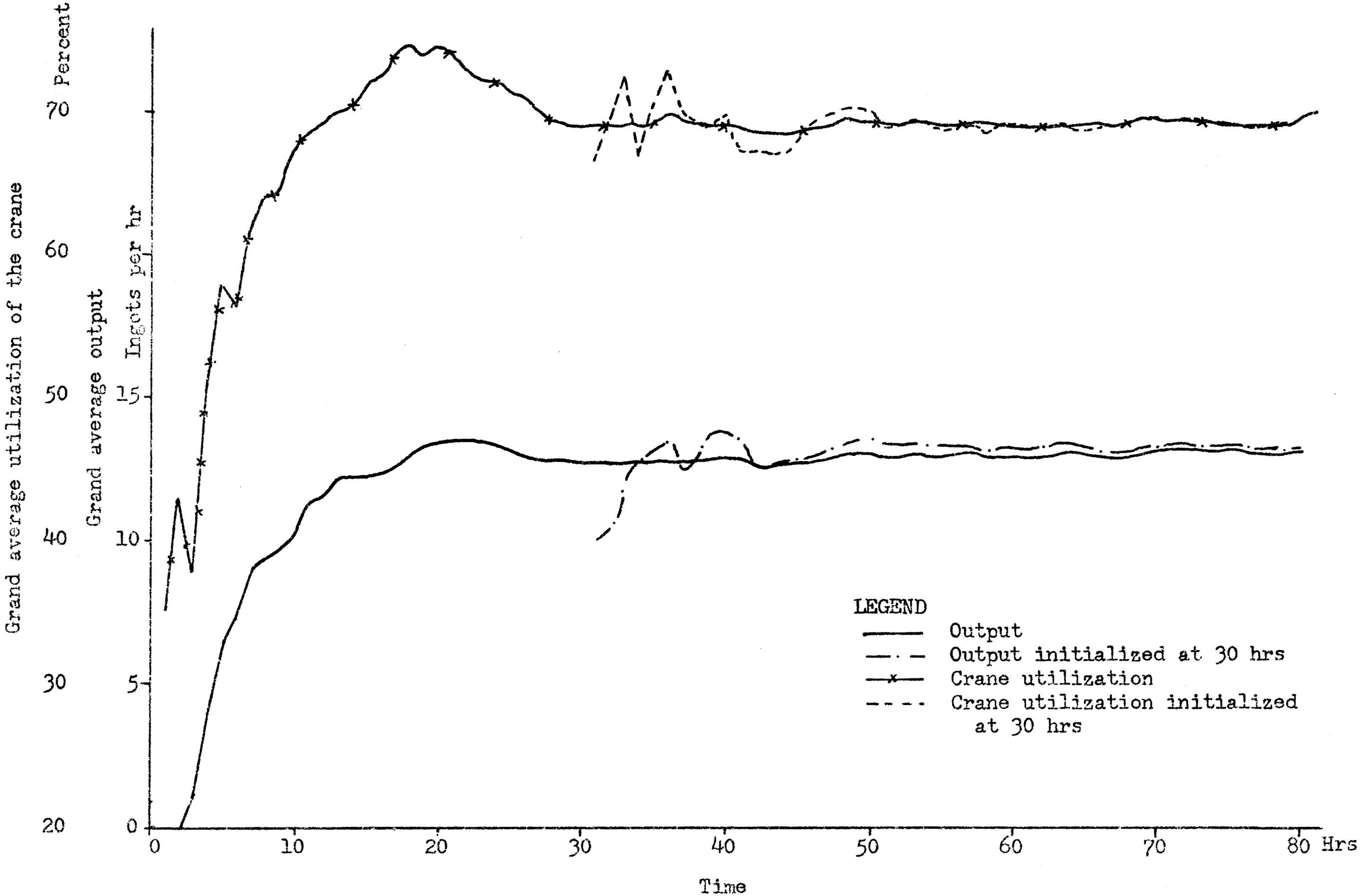

Fig. 5. The grand average utilization of the crane and the grand average output of the soaked ingots: Model 4/(37)

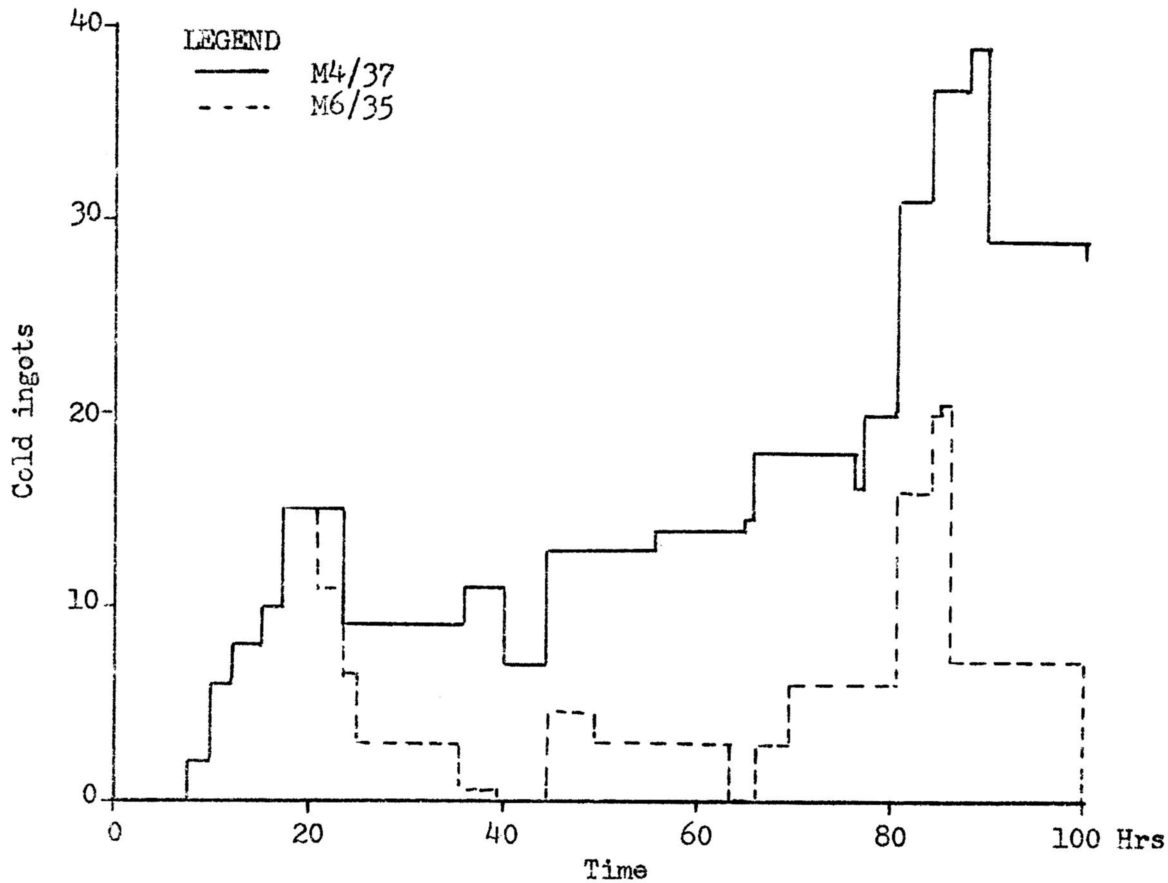

Fig. 6. Cold ingots on hand: Model 4/(37), Model 6/(35)

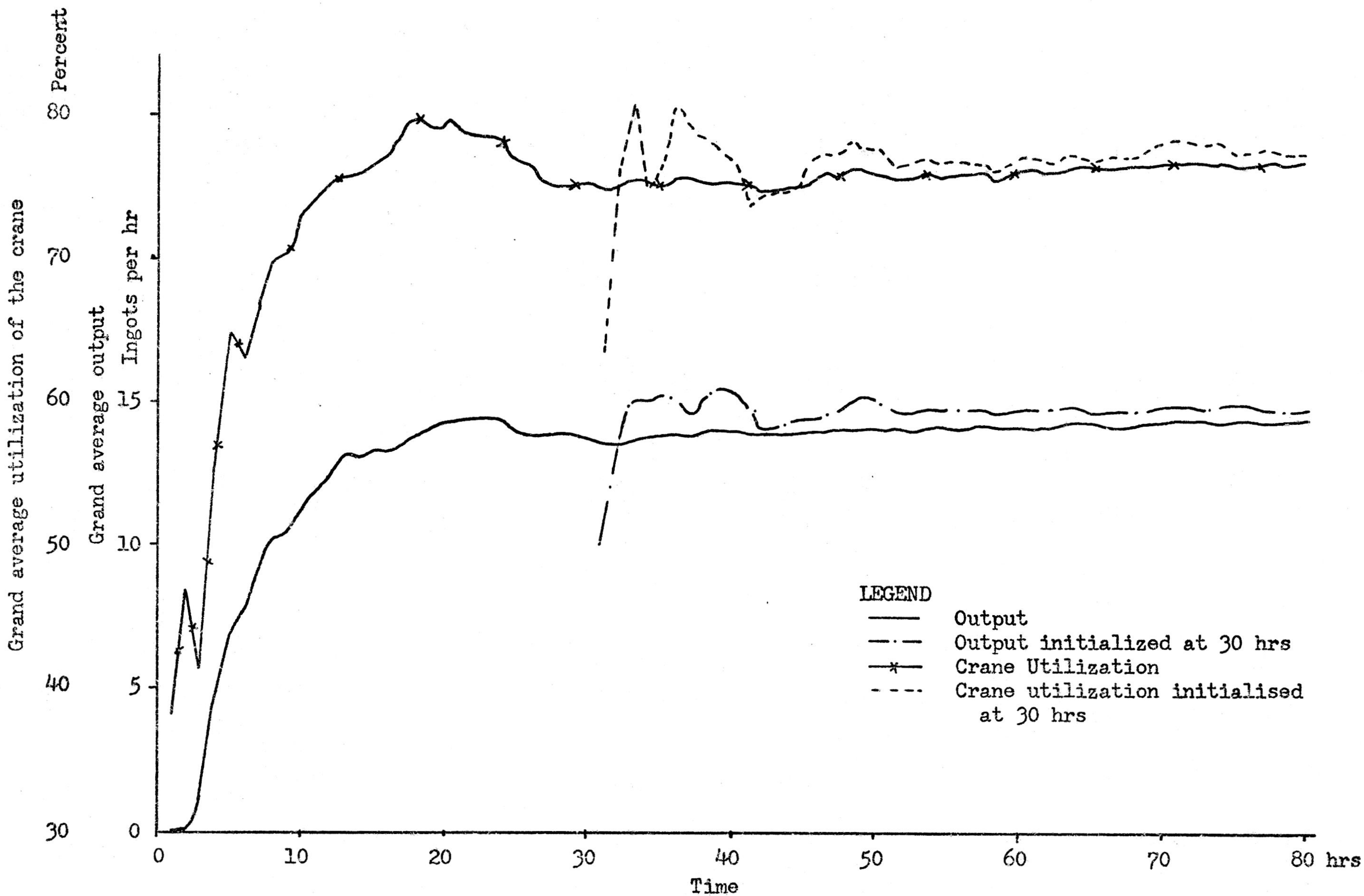

Fig. 7. The grand average utilization of the crane and the grand average output of the soaked ingots: Model 6/(39)

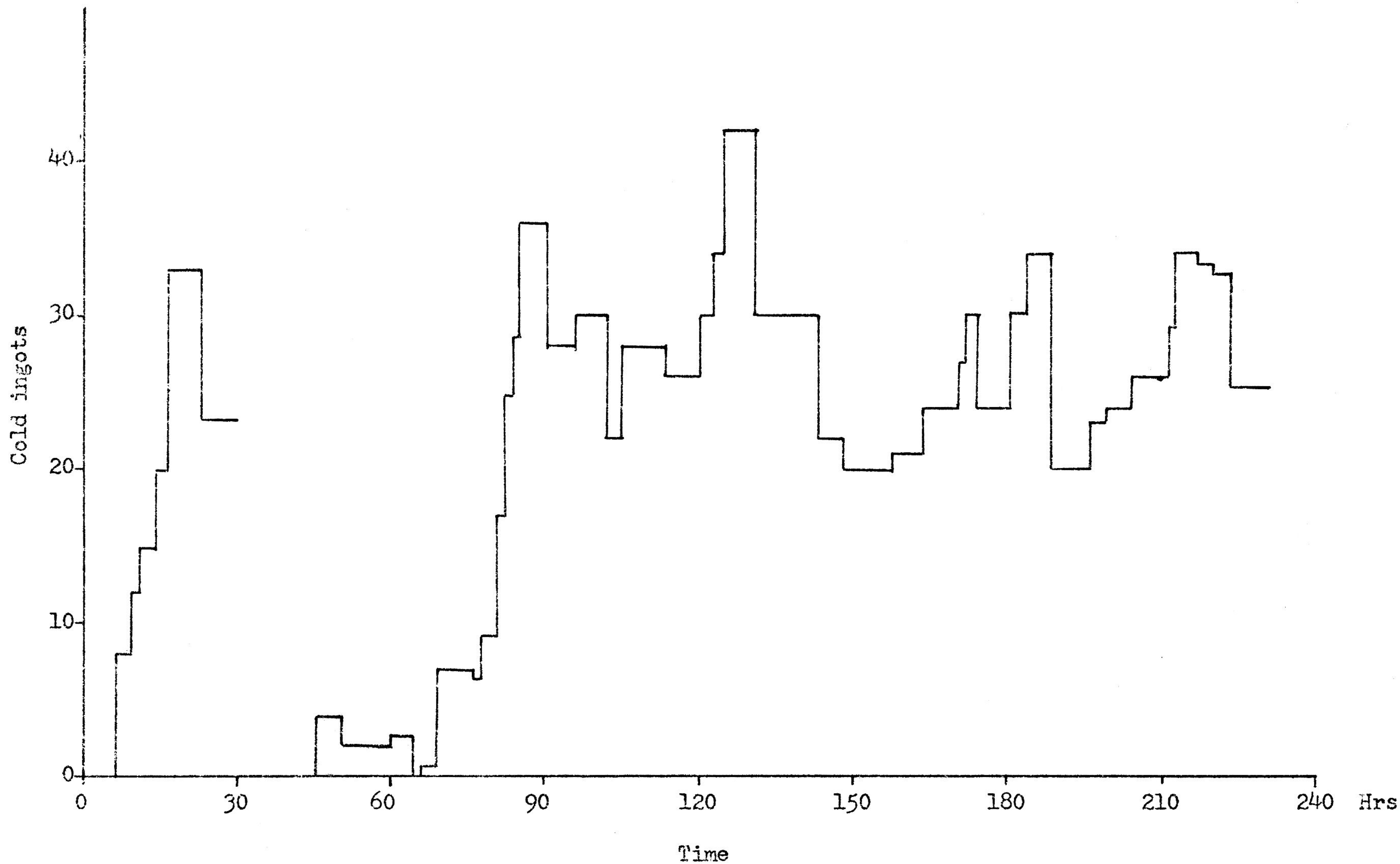

Fig. 8. Cold ingots on hand: Model 6/(39)

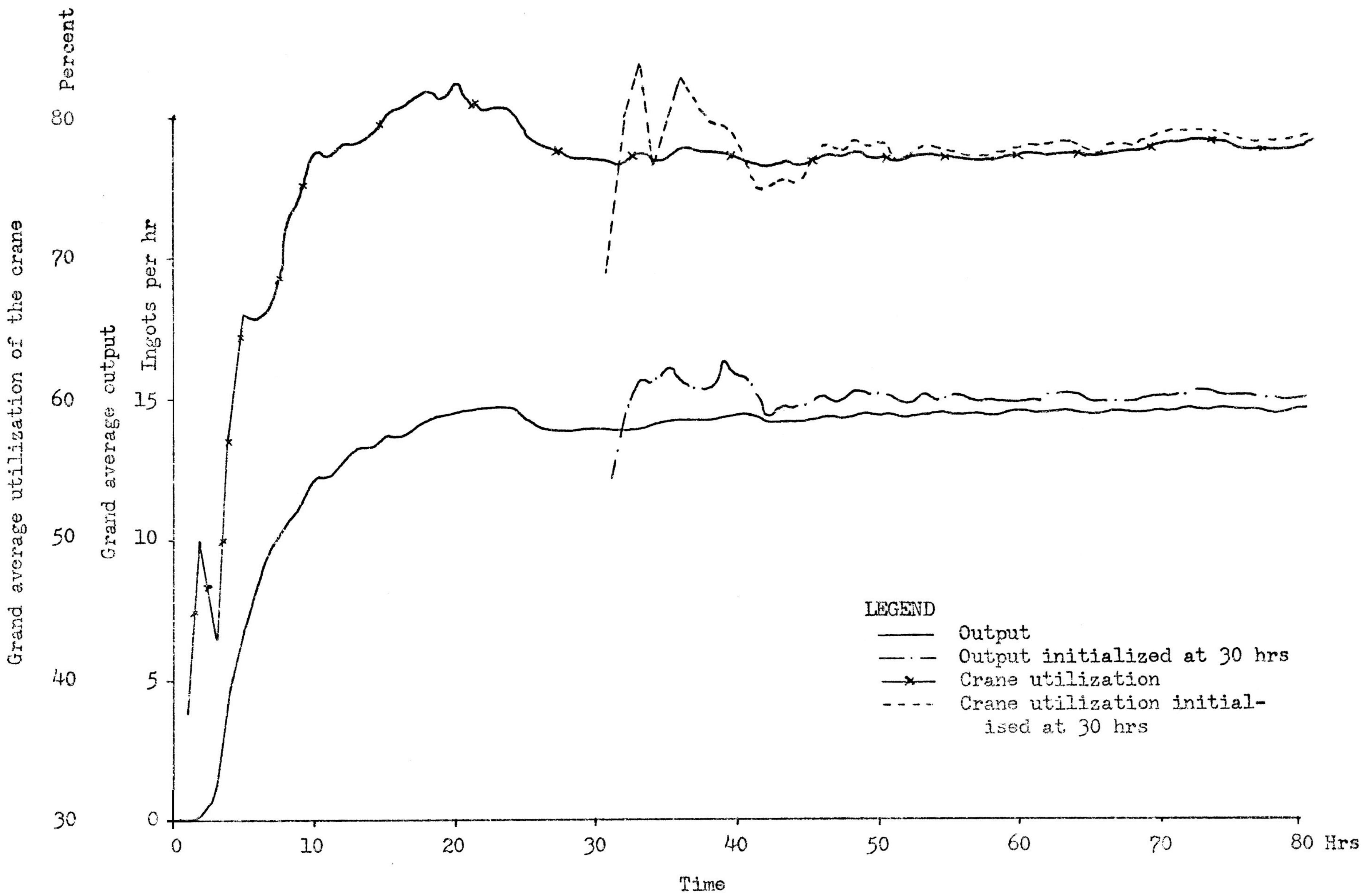

Fig. 9. The grand average utilization of the crane and the grand average output of the soaked ingots: Model 6/(40)

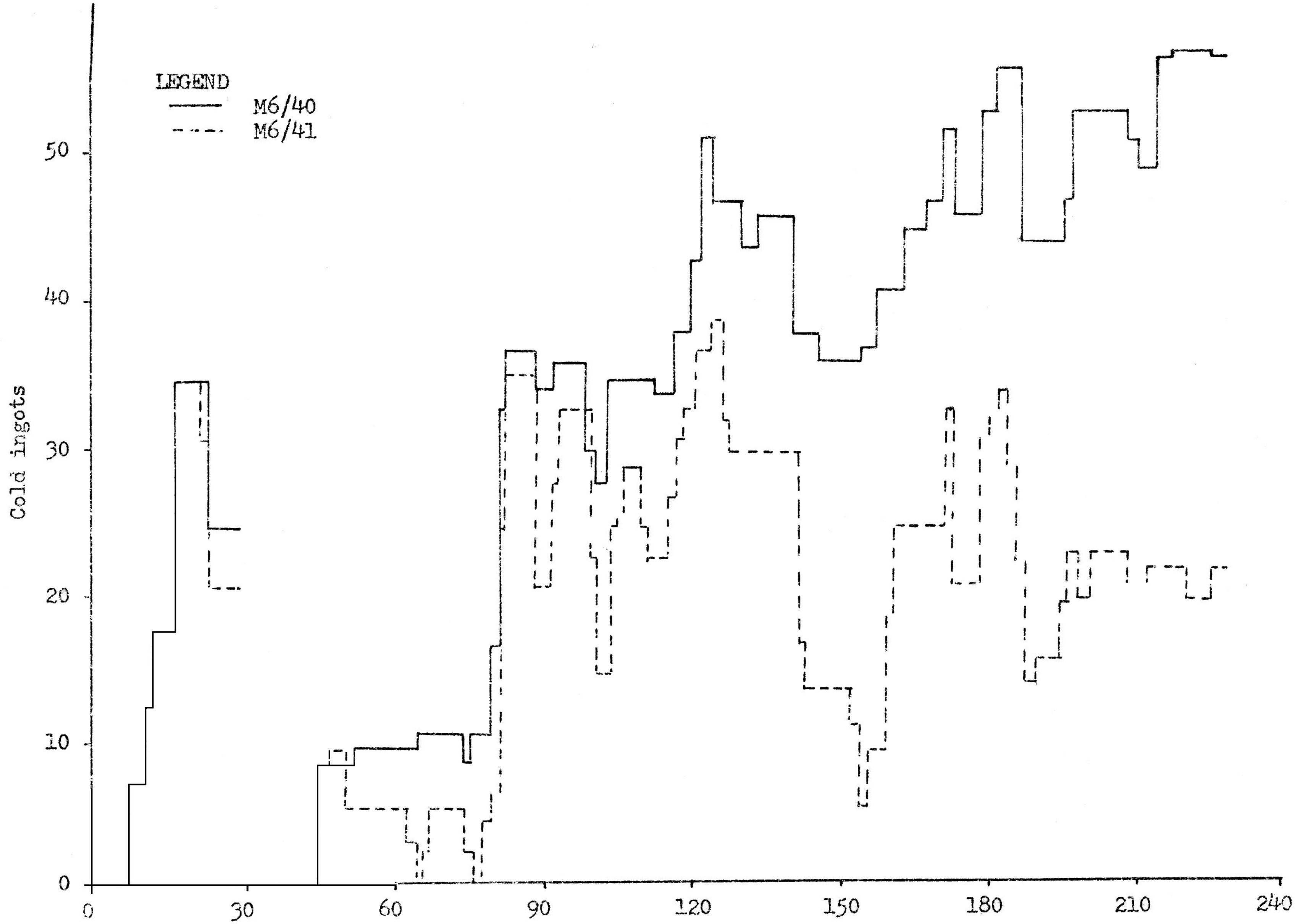

Fig. 10. Cold ingots on hand: Model 6/(40, 41)

5-2. PRIORITY RATIO

Only one crane is used in the soaking pit operation. It is used in charging cold ingots, charging arriving ingots and drawing heated ingots. The ingots are removed after being heated, irrespective of the rolling requirements, if the crane is available. In these circumstances a method has to be specified for crane operation. A discussion, in general terms, on the effect of crane operation on the output is made in the introduction. The ratio of the number of empty cells to the total number of cells is used as a criterion in determining the type of crane operation. This is referred to here as the priority ratio.

There are two fractions which specify either the drawing of soaked ingots or the charging of arriving ingots or cold ingots. This is shown in the Fig. 11. If the ratio of empty cells to the total cells at a particular instance is less than FRAC 2, the crane will draw soaked ingots; of course there should be soaked ingots ready to be drawn. Otherwise it will charge the arriving ingots available. If the ratio is between FRAC 2 and FRAC 1, the crane will charge arriving ingots first and then draw the soaked ingots. If the ratio is greater than FRAC 1, the crane will charge cold ingots first. If they are not available, it will charge arriving ingots and after that it will draw the soaked ingots.

The number of empty cells, NQ(4), is a GASP variable, and is available at any instant. The capacity of the soaking pit, that is, the total number of cells, is read initially in the main program. It is also in the common storage. So at a particular instant, the ratio of the number of empty cells to the total number of cells can be calculated. This is then used in determining the type of operation for the crane. Whenever the two fractions are

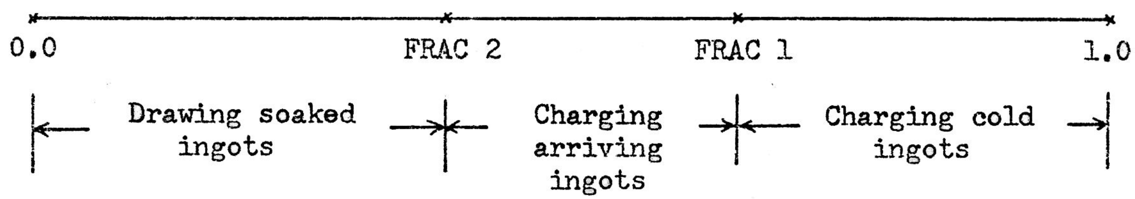

Fig. 11. Fraction of the cells empty

simultaneously referred to in the program, the first one is FRAC 2--which determines either drawing a soaked ingot or charging an arriving ingot--, and the second one is FRAC 1--which determines either the charging of cold ingots or charging of arriving ingots.

Model 3/(14, 8). By changing FRAC 2 from 0.2 to 0.4, a smoother output of ingots and a better time between departures of soaked ingots is achieved. Table 1 shows the output for the two runs. With FRAC 2 equal to 0.4, the waiting time for arriving ingots has increased and the waiting time for the soaked ingots has decreased. The waiting time in turn effects the heating time by increasing the track time. Here the increase in the heating time (service time of the cell) is compensated by the decrease in waiting time for the soaked ingots. So there is no change in the block time, that is, the time the ingot occupies the cell and block the service for the next ingot.

There is an important distinction between the service time and the block time [14]. The interval between the instant at which a customer begins to receive the service and that at which this service ends is known as his service time. Here it is equal to the theoritical heating time of an ingot. The interval that elapses between the instant at which the service time of the next customer begins, when the second customer has been in the queue waiting for service is known as block time. The block time may be thought of as the total time for which one ingot denies service to the next, by blocking out a cell. So, in determining the number of cells required, the block time should be considered instead of the heating time.

Model 6/(25, 28). The FRAC 2 is increased from 0.40 to 0.55. The output is shown in Table 2. Giving excess priority to drawing soaked ingots doesn't seem to be a better policy. Definitely, it reduces the waiting time

TABLE 1

OUTPUT SUMMARY FOR MODEL 3/(14, 8)

Model / Run	FRAC 2	Output/hr ingots: Mean	Output/hr ingots: Std-dev / Mean	T.B.D: Std-dev / Mean	Waiting time for arriving ingots, min: Mean	Waiting time for arriving ingots, min: Std-dev	Waiting time for soaked ingots, min: Mean	Waiting time for soaked ingots, min: Std-dev	Theoretical heating time, hrs	Block time hrs
M3/14	0.20	13.56	0.37	1.28	7.75	12.00	3.59	4.58	2.89	2.95
M3/8	0.40	13.55	0.35	1.03	9.01	13.21	1.92	3.01	2.93	2.96

TABLE 2

OUTPUT SUMMARY FOR MODEL 6/(25, 28)

Model / Run	FRAC 2	Output of ingots/hr: Mean	Output of ingots/hr: Std-dev / Mean	T.B.D: Std-dev / Mean	Waiting time in minutes: Arriving ingots	Waiting time in minutes: Soaked ingots	Cold ingots created	Cold ingots charged
M6/25	0.40	13.04	0.36	1.16	9.20	2.12	210.00	40.00
M6/28	0.55	12.83	0.38	1.18	9.50	1.30	243.00	52.00

for soaked ingots. Because of a high priority for removing soaked ingots, more cold ingots are created in the system. It is better to remove ingots when the crane has spare time. The heated ingots should not wait too long. Increasing FRAC 2 didn't effect the coefficient of variation of time between departures from the system. But it increased the variation in output of ingots per hour.

Model 6/(31, 35). FRAC 1 is reduced from 0.6 to 0.5; that is cold ingots are charged even when half the pit is empty, instead of when 6/10ths of the pit is empty. There is a lesser variation in the output of ingots per hour and the time between departures of ingots from the system. But the significant affect of this change is in the ability of the system to charge all the ingots created, Table 3. Because of charging cold ingots the utilization of the pit has increased. Maximum utilization of the pit has also reached 100 percent.

From the above discussion it can be concluded that at certain values of the two fractions, best results can be achieved. With the increase in the utilization of the capacity of the soaking pit, lower values should be selected. The exact values depend upon the inter-arrival time for ingots, soaking pit capacity, crane availability and heating times.

5-3. TIME BETWEEN DEPARTURES OF INGOTS FROM THE SOAKING PIT

Time between departures of ingots from the system, referred to as T.B.D, is a measure of the output of the system. Fig. 12 shows a graph plotted between T.B.D in minutes, and the frequency of occurance. When T.B.D was plotted with 0.5 minutes interval, the nature of the distribution is not easily understood. There were two more relative maximum in addition to an absolute maximum value. It was occuring in all of the models even after changes in the values of different variables. The only difference was in the intensity of the high and low values.

Afterwards it was thought that the intervel selected for plotting the graph was very fine. Such a fine intervel doesn't seem to have any practical significance. So the same relationship was plotted with 1 minute intervel of T.B.D. As shown in Fig. 12, it did smooth the distribution. Still a low value was obtained after the maximum value in all the models. A fuller understanding of the distribution was not realised. This also raises the question of smoothing out the distributions by taking coarser intervels. Obviously the effect of the next low value can be completely ignored by taking an intervel of 2 minutes. This completely ignores the problem.

The next step in understanding the distribution was made by looking at the operating system. Even though the ingot is ready after being heated, it has to be serviced by the crane. The crane picks up the heated ingot and deposits it on the ingot chariot. It takes a definite amount of time. Under any circumstance the time between departures can't be less than the crane service time. So it was considered more reasonable to plot the graph with a frequency intervel equal to one unit of the average crane service time. The distribution smoothes out after attaining a maximum value.

To understand the effect of the crane time on time between departures of ingots, the average crane time was changed from 1.5 minutes to 1.0 minutes and then to 2 minutes. Fig. 13 shows the three distributions plotted in minutes, with an intervel equal to a crane service time. This raised another question of plotting the distributions. This is dependent on crane time and it is difficult to compare the distributions if they are plotted in minutes.

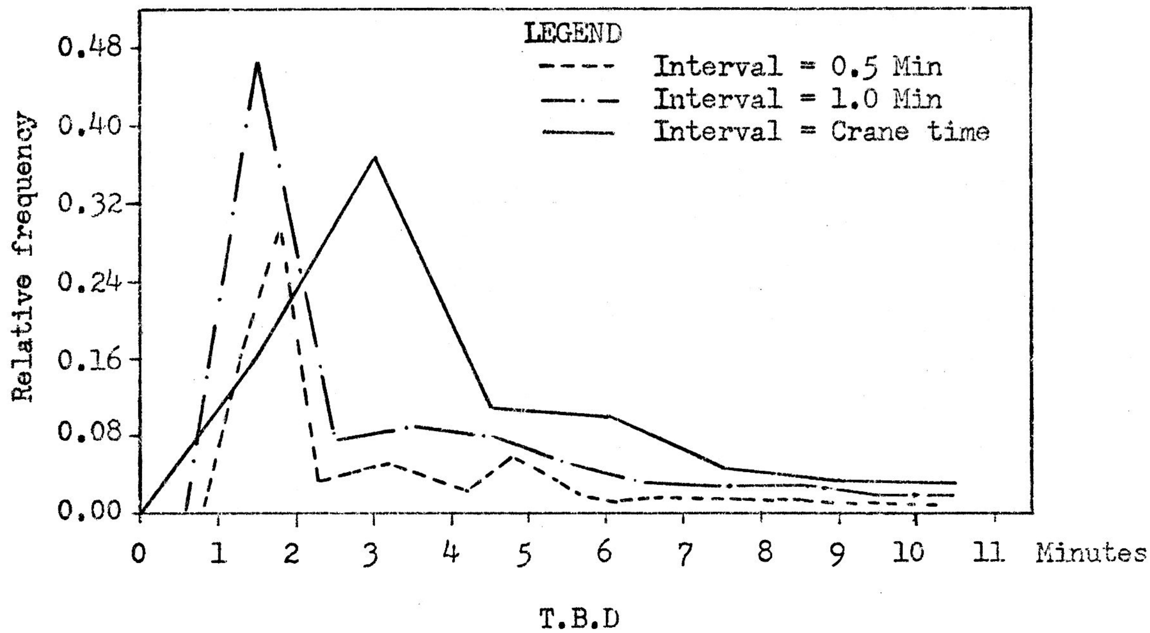

Fig. 12. Distribution of T.B.D: Model 6/(29)

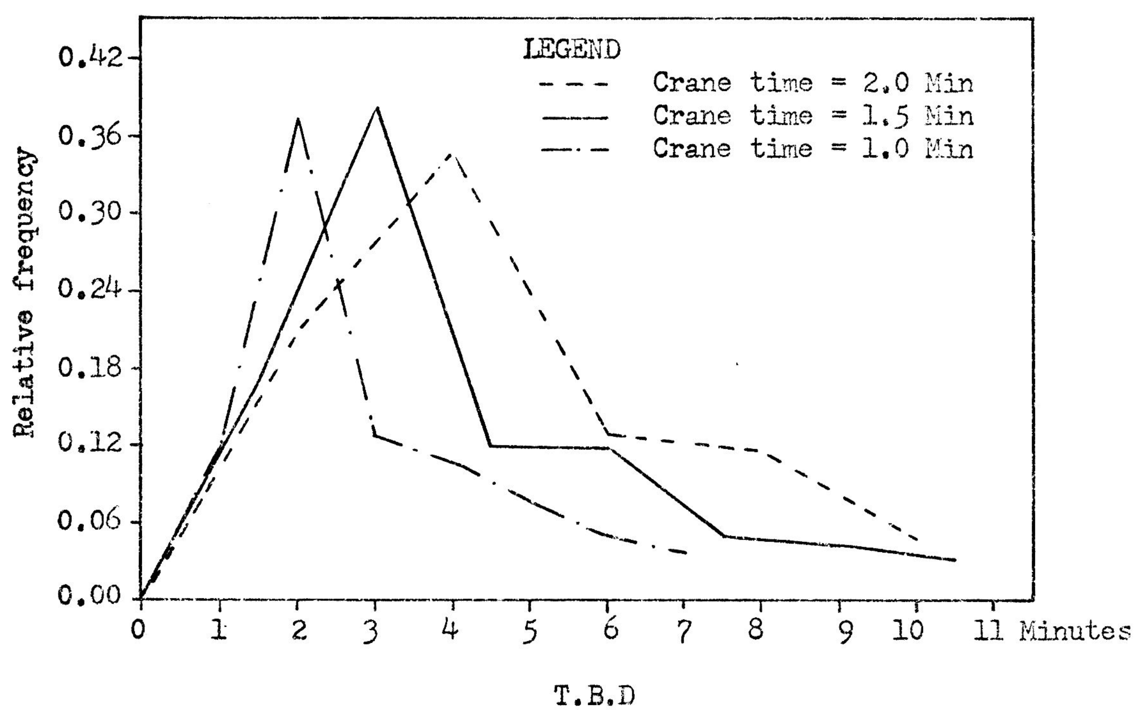

Fig. 13. Distribution of T.B.D: Model 6/(31, 27, 32)

So it was decided to plot the distribution in units of crane time so that it will be independent of the crane time. Fig. 14 shows the above runs plotted in units of crane time.

Time between departures from the system is effected by the inter-arrival times of ingots, capacity of the pit, utilization of the pit and availability and use of the crane. Crane time for charging an ingot is greater than that of drawing an ingot from the soaking pit, because of the differences in travel distances. The crane time for charging an ingot either increases or decreases the heating time for the next ingot. Table 4 shows the change in heating time for the next ingot. These values are obtained from the heating time curve. Even if the ingot is ready after being heated, it has to wait for the crane.

Model 3/(14). The fractions which determine the priority for the crane, also affect the time between departures. When FRAC 2 is 0.2, the crane gives priority for charging the arriving ingots most of the time. So the crane will complete the charging of arriving ingots--about 7 ingots--and then it will draw the heated ingots. That is why the frequencies are higher with T.B.D equal to 7 and 8 units of crane time, Fig. 15.

Model 6/(23, 31). The arrival pattern of ingots--single or bulk--affects the distribution of T.B.D. If one ingot per train arrives, the frequency with T.B.D equal to three units of crane time is significantly higher when compared to bulk arrival of ingots; the maximum value occuring at two units of crane time is lower. Most of the time, only one or two arriving ingots may be waiting for the crane. The crane will service the arriving ingots first because of the priority ratio; then it will draw the soaked ingots, Fig. 16.

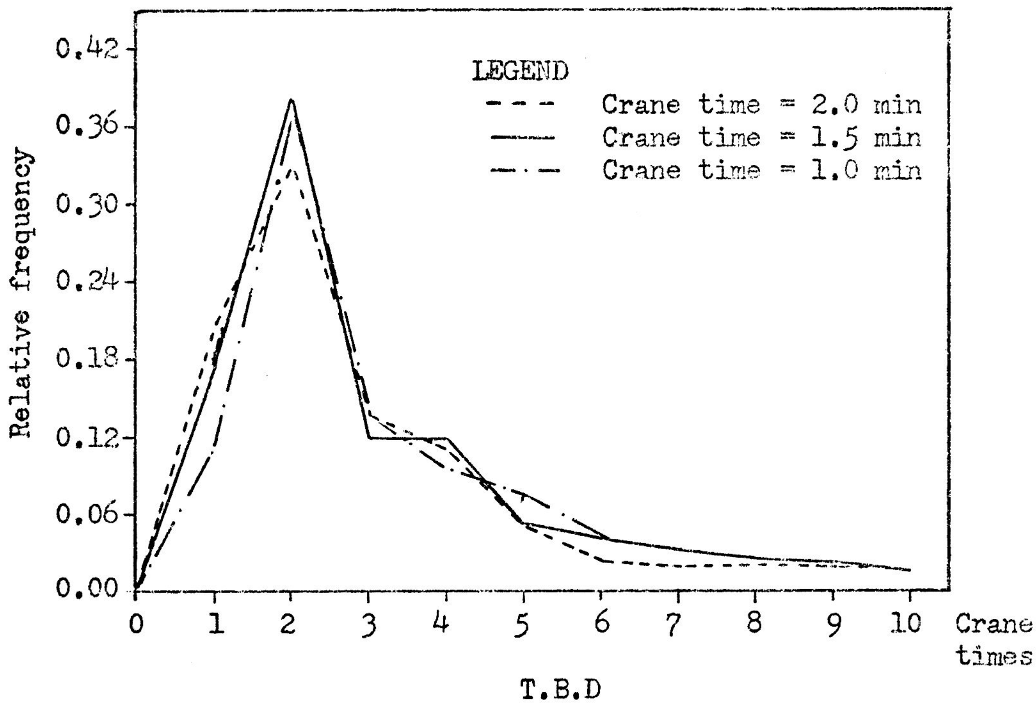

Fig. 14. Distribution of T.B.D, plotted in units of crane time: Model 6/(31, 27, 32)

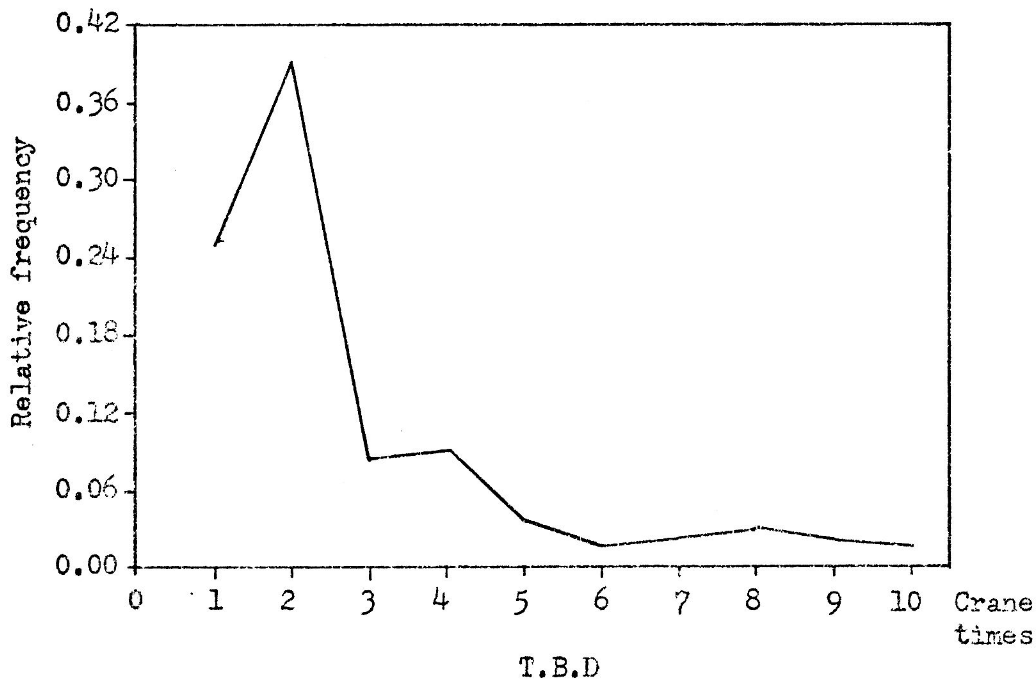

Fig. 15. Distribution of T.B.D: Model 3/(14)

TABLE 3

OUTPUT SUMMARY FOR MODEL 6/(31, 35)

Model / Run	FRAC 1	Output of ingots per hr: Mean	Output of ingots per hr: Std-dev / Mean	Utilization of the pit, percent: Average	Utilization of the pit, percent: Max.	T.B.D: Std-dev / Mean	Cold ingots created	Cold ingots charged
M6/31	0.60	13.61	0.27	66.00	95.00	1.03	52.00	26.00
M6/35	0.50	13.82	0.26	74.00	100.00	1.02	50.00	50.00

TABLE 4

CHANGE IN THE HEATING TIME FOR THE NEXT INGOT CAUSED BY THE CRANE SERVICING AN ARRIVING INGOT

Ingot track time measured from the origin of the heating curve, hrs	0.000	0.5000	1.500
Change in the heating time for the next ingot when the crane is charging an ingot, minutes	-4.620	+0.132	+9.560

Another interesting phenomenon will occur, when the pit is working at the priority ratio which decides the charging or drawing of ingots--FRAC 2. The crane will be charging arriving ingots and drawing soaked ingots alternately. Then the time between departures is equal to two crane service times. This is true also when there are no arriving ingots to be charged and the crane is operating at the priority ratio which specifies charging cold ingots--FRAC 1.

The time between departures is also a function of inter-arrival times and the number of ingots arriving. Sometimes there is a large difference in time between charging of the last ingot on the previous train and charging the first ingot on the present train. This is reflected in the time between departures of ingots. Fig. 17 shows two distributions of T.B.D with different inter-arrival times--run number 34 is with constant inter-arrival times and run number 31 is with Erlang 4. With constant inter-arrival times, the empty cells have a mean of 22.8 and a standard deviation of 2.5. The crane is working at the priority ratio which decides the charging of arriving ingots or drawing of the soaked ingots for a significant amount of time. That is why, the frequency with two units of crane time is lower and frequencies with three and four units of crane time are higher when compared to run number 34.

Model 3/(8, 12). In run number 8 on the average 7 ingots are arriving at the soaking pit at half an hour interval; but in run number 12, 8 ingots are arriving at half an hour interval. The capacity of the pit is not sufficient. So when 8 ingots are arriving, the crane is giving priority to drawing soaked ingots. So all the increase in frequency in the T.B.D occured at three units of crane time.

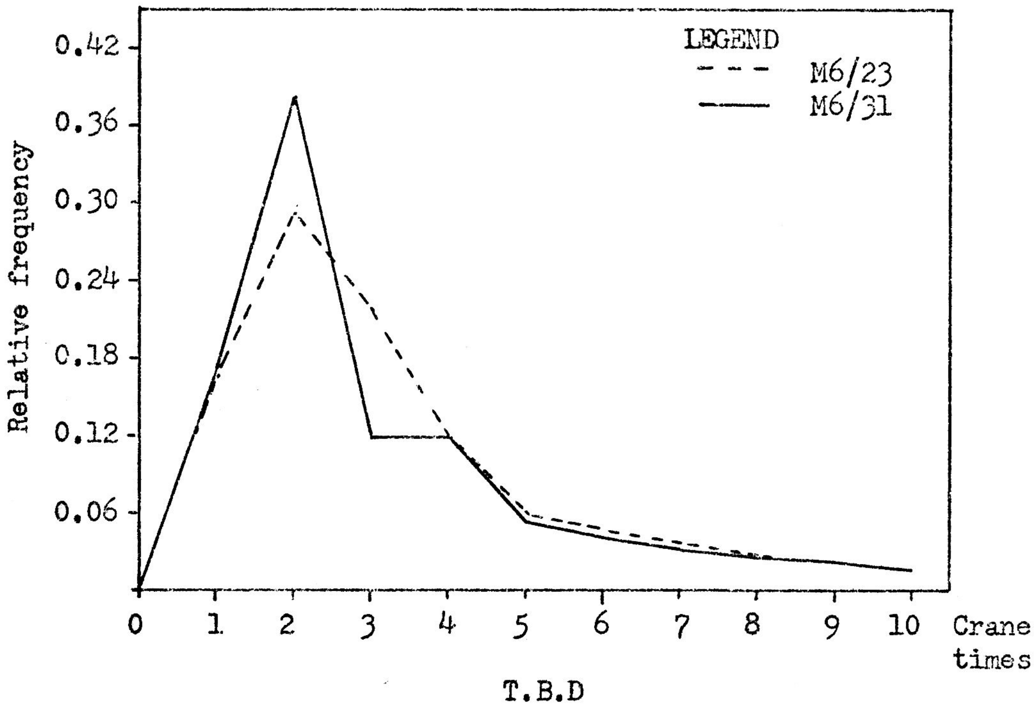

Fig. 16. Distribution of T.B.D: Model 6/(23, 31)

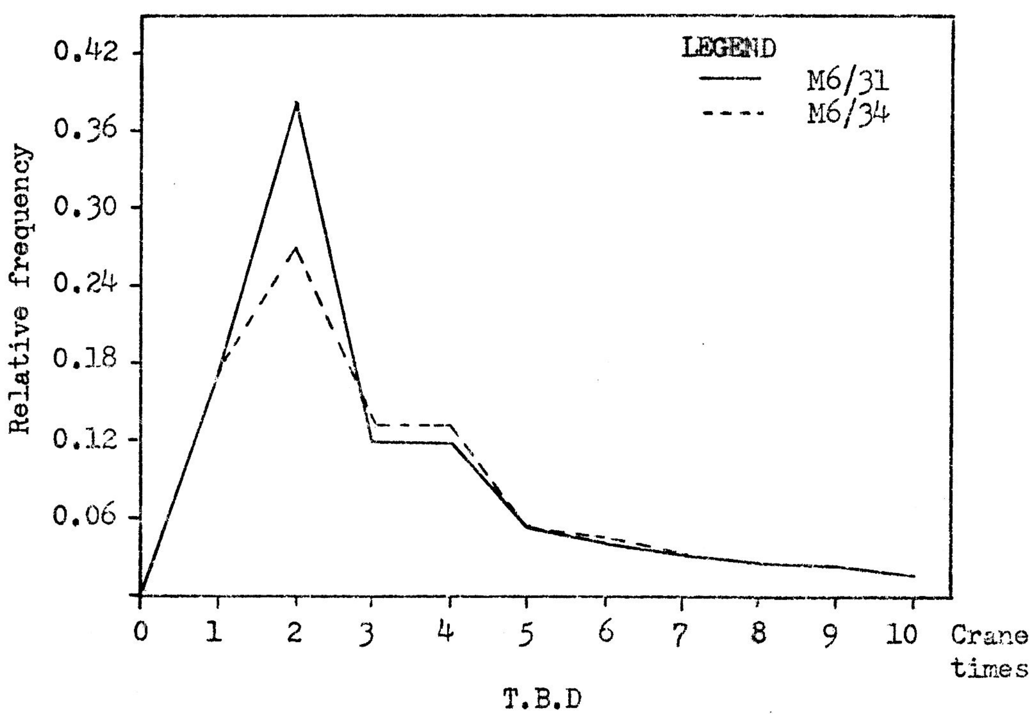

Fig. 17. Distribution of T.B.D: Model 6/(31, 34)

Figure 19 shows a cumulative distribution of the time between departures from the system.

The crane service time for soaked ingots is approximately normal with a mean of 1.5 minutes and a standard deviation of 0.2 minutes. The frequencies of time between departures are collected with an interval equal to the average crane time. This implies that a fraction of the frequency with time between departures equal to one crane time are counted along with two units of crane time. This is not so clear for other units of crane times because of interactions which can't be correctly estimated.

A great amount of time was spent in understanding the distribution of time between departures of ingots from the system. A finer interval of 0.5 minutes was selected in the hope of understanding the distribution. The fact is that the width of the interval is governed by the crane time which is about 1.5 minutes. In collecting histograms, it will be advantageous to give proper thought to the parameters which affect the variable under consideration. A finer interval will not always help to understand the problem.

5-4. OUTPUT OF INGOTS PER HOUR

5-4-1. Relation between the output of ingots per hour and the time between departures from the system.

A variation in the output is directly reflected in the variation of time between departures of ingots from the system, Table 5. Fig. 20 shows the relationship between the coefficient of variations of the output of ingots per hour and the time between departures of ingots from the system. They are significantly correlated. Product moment coefficient of linear correlation is 0.887.

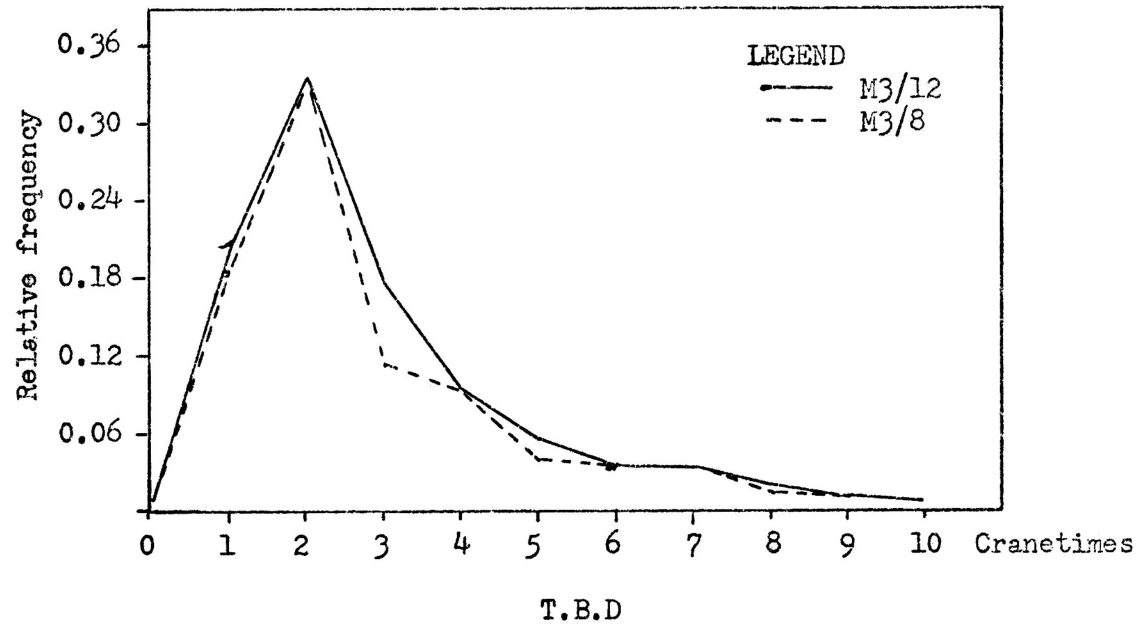

Fig. 18. Distribution of T.B.D: Model 3/(8, 12)

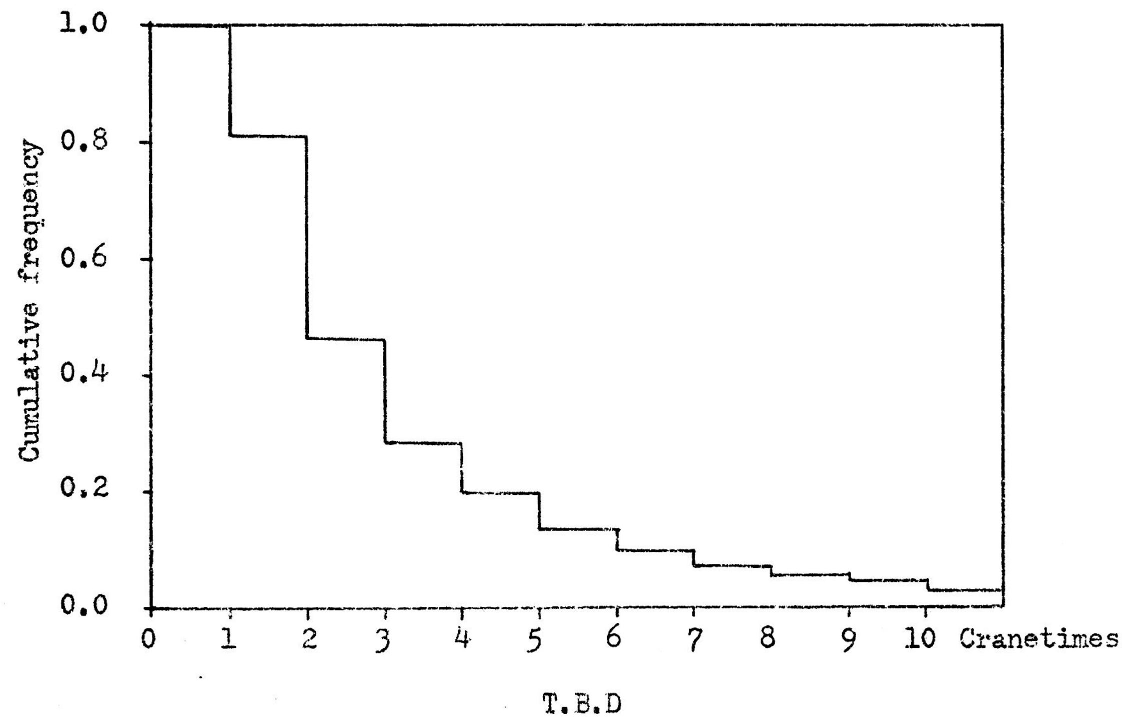

Fig. 19. Cumulative distribution of T.B.D: Model 3/(8, 12)

TABLE 5

LINEAR REGRESSION OF T.B.D ON OUTPUT

S.No.	Model / Run	Coeff. of variation: Output X	Coeff. of variation: T.B.D Y
1.	M5/21	0.304	1.000
2.	M5/22	0.355	1.015
3.	M6/23	0.236	0.850
4.	M6/24	0.256	0.984
5.	M6/25	0.362	1.160
6.	M6/26	0.357	1.150
7.	M6/27	0.460	1.420
8.	M6/28	0.382	1.180
9.	M6/29	0.286	1.040
10.	M6/30	0.266	1.030
11.	M6/31	0.268	1.032
12.	M6/32	0.229	0.945

$Y_i = 0.47 + 1.91 X_i$

r = product moment coefficient of linear correlation = 0.887

To test

H_0 ($\rho = 0$) against Ha ($\rho \neq 0$)

$$t = \frac{r - 0}{\sqrt{\frac{1 - r^2}{n - 2}}} \qquad D.F = n - 2$$

$$= 6.06 \qquad D.F = 10$$

So the hypothesis H_0 ($\rho = 0$) is rejected.

5-4-2. The effect of the inter-arrival distribution of ingots.

The distributions of the inter-arrival times for the trains is varied, keeping all the other parameters fixed. Model 6/(34, 24, 31, 25). Table 6 shows the output. By reducing the variation in the inter-arrival times for the trains, less variation in the output per hour and the time between departures is achieved; cold ingots created have decreased and the system was able to charge all the cold ingots created. In fact when a constant inter-arrival time is achieved, the capacity of the pit can be reduced by 22 percent and still can achieve the same output. No cold ingots are created in the system, that is, all the arriving ingots are charged within two hours after their arrival. Since cold ingots are not created, the pit can be used more efficiently. It should be remembered that 3.18 arriving ingots can be heated in a cell during the time a cold ingot is heated. Because of a short waiting time, heating time is also decreased. The fluctuations in the crane utilization is less--minimum value is 55 percent and maximum value is 80 percent. Thus the crane is available for use during each hour. Standard deviation of the number of empty cells has decreased. By assuming a constant inter-arrival time a major source of variation is eliminated. Fig. 21 shows the relation between the heating time and the type of distribution.

5-4-3. The effect of the batch size of ingots.

The number of ingots arriving per hour is kept constant. The size of the batch is reduced and the inter-arrival time for the trains is decreased. There is a significant effect on the operating characteristics of the system. With the reduction in the batch size, the variations in the output per hour and the time between departures decreased. Waiting time for arriving ingots

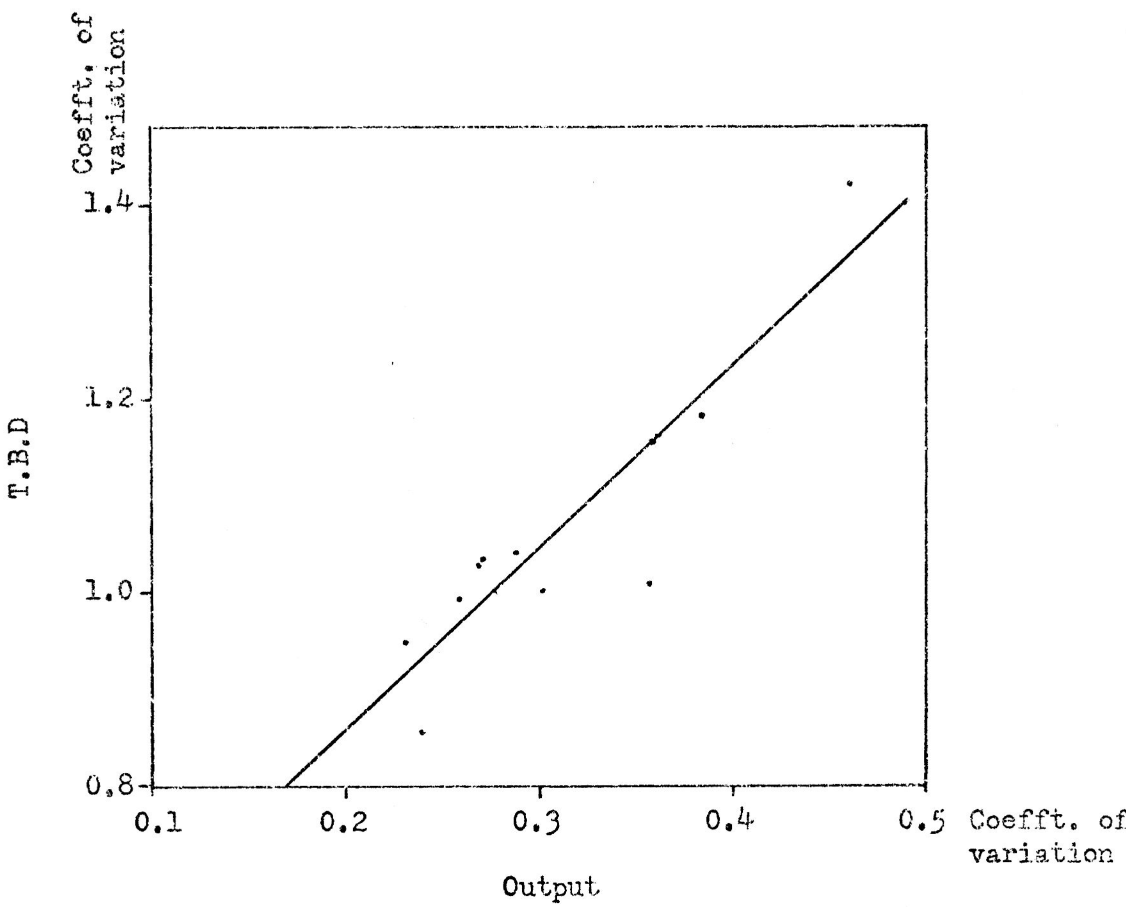

Fig. 20. Relation between T.B.D and output of ingots

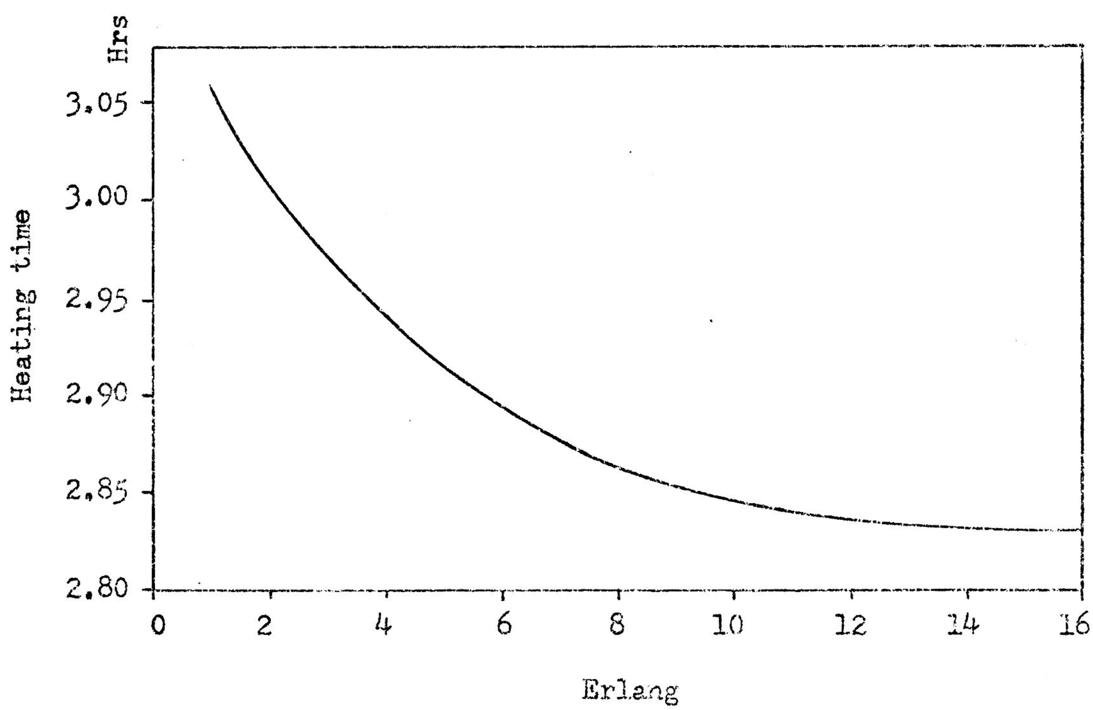

Fig. 21. Relation between heating time and type of distribution

and soaked ingots have decreased. Table 7 shows the output for Model 6/(9, 4). In the above two runs, the batch size is reduced from 14 to 7. Fewer cold ingots are created and all are charged into the soaking pit.

Model 3/(8, 18, 19): 7, 4.67 and 3.5 ingots per train are assumed. In this model cold ingots are not created. So the effect of it on the system is unknown. The maximum number of arriving ingots waiting for the crane has decreased with smaller batch sizes, Table 8. Even though the empty cells have increased, the actual percentage increase in the capacity achieved with smaller batch size is unknown, because of the inability to maintain a constant input to the system. The heating time can be considered as a measure of the increase in the capacity of the soaking pit. If the heating time is less, more ingots can be heated in the soaking pit.

Model 6/(23, 25): both the runs have an exponential distribution of inter-arrival times for the trains. But in run No. 23, one ingot per train is assumed instead of the bulk arrival. Cold ingots created in the system have decreased. But it was not able to charge any cold ingot, because the maximum number of empty cells is only 35. For charging cold ingots empty cells should be more than 36. The maximum utilization of the soaking pit is 93.3 percent, when one ingot per train arrives. There is a 10 percent increase in the capacity of the soaking pit, as calculated from the reduction in the heating time. The standard deviation of the heating time is approximately equal to the standard deviation of the variation in the track time that is assumed in the problem, since the waiting time for the arriving ingots is insignificant. By assuming a single arrival, one of the variables, the waiting time for heated ingots, has been kept under control, Table 9.

Fig. 22 shows the heating time plotted against the batch size of ingots.

TABLE 6

OUTPUT SUMMARY FOR MODEL 6/(34, 24, 31, 25)

Model Run	Inter-arrival distn. of trains	Total no. of ingots arriving at the pit	Output of ingots per hr.		Heating time, hrs.	Utilization of the pit, per-cent		Empty cells Std-dev	Cold ingots created	Cold ingots charged	T.B.D Std-dev/Mean
			Mean	Std-dev/Mean		Average	Max.				
M6/34	const	1238.00	13.03	0.16	2.83	62.00	78.40	2.50	0.00	0.00	0.94
M6/24	ER-8	1256.00	13.13	0.26	2.86	64.30	98.30	6.30	8.00	8.00	0.98
M6/31	ER-4	1317.00	13.61	0.27	2.94	67.20	95.00	7.20	52.00	26.00	1.03
M6/25	ER-1	1439.00	13.04	0.36	3.06	66.70	100.00	8.66	210.00	40.00	1.16

TABLE 7

OUTPUT SUMMARY FOR MODEL 1/(9, 4)

Model Run	Inter-arrival time, hrs.	No. of ingots on a train	Output of ingots per hr.		T.B.D Std-dev	Heating time, hrs.	Waiting time in minutes		Cold ingots created	Cold ingots charged
			Mean	Std-dev/Mean			Arriving ingots	Soaked ingots		
M1/9	1.00	14.00	13.53	0.35	1.30	3.23	14.51	5.90	92.00	44.00
M1/4	0.50	7.00	13.49	0.33	1.11	2.94	5.36	3.80	32.00	32.00

TABLE 8

OUTPUT SUMMARY FOR MODEL 3/(8, 18, 19)

Model Run	Inter-arrival times, hrs.	No. of ingots on a train	Output of ingots per hr.		T.B.D Std-dev / Mean	Heating time, hrs	Max. arriving ingots waiting	Empty cells	Waiting time in minutes	
			Mean	Std-dev / Mean					Arriving ingots	Soaked ingots
M3/8	0.50	7.00	13.55	0.35	1.35	2.93	16.00	18.61	9.01	1.92
M3/18	0.33	4.67	12.54	0.32	1.04	2.79	13.00	23.30	4.31	1.47
M3/19	0.25	3.50	11.92	0.31	0.94	2.76	8.00	25.20	2.30	1.28

TABLE 9

OUTPUT SUMMARY FOR MODEL 6/(23, 25)

Model Run	No. of ingots per train	Output of ingots per hr.		T.B.D Std-dev / Mean	Heating time, hrs.		Empty cells		Cold ingots created	Cold ingots charged	Arriving ingots waiting time
		Mean	Std-dev / Mean		Mean	Std-dev	Mean	Min.			
M6/23	1.00	13.43	0.23	0.85	2.75	0.34	22.30	4.00	112.00	0.00	0.84
M6/25	7.00	13.04	0.36	1.16	3.06	1.10	19.90	0.00	210.00	40.00	9.20

From the above, it can be predicted that getting the ingots in small quantities, will give a better over-all performance for the soaking pit. But this requires an increase in the number of locomotives at an additional investment. Further this may create traffic bottlenecks. Another constraint is the amount of metal produced at a time in the steel making furnace and the production interval--characteristics of the furnace. The train loads can be specified as a fraction of the total pit capacity instead of the ingots.

5-4-4. The effect of the priority ratio.

Giving a higher priority for drawing heated ingots doesn't seem to be a better policy when the soaking pit is not fully utilized. Model 6/(25, 28). This was discussed under priority ratio.

As discussed earlier, after decreasing FRAC 1, for charging cold ingots, from 0.6 to 0.5, the system was able to charge all the cold ingots. Model 6/(31, 35) with the increase in the utilization of the pit, the two fractions FRAC 1 and FRAC 2 should be decreased. But there is a limit beyond which the effect of the decrease in the values is negligible. In fact, FRAC 1, for charging cold ingots, has a negative effect on the system. It increases the cold ingots created in the system by 50 percent, which effects the economy of the soaking pit operation. The output for model 6/(40, 41) is shown below:

model/run	cold ingots created	cold ingots charged
M6/40	118.00	66.00
M6/41	173.00	147.00

5-4-5. The effect of the insufficient soaking pit capacity.

Model 5/(22, 26): in run No. 26, the capacity of the pit is increased from 60 cells to 70 cells. The length of the pit is increased to 58'. The maximum number of arriving ingots waiting for the crane have decreased. By the end of the simulation run all of the waiting ingots are charged. Since fewer arriving ingots are waiting, the average waiting time is less. This decreases the heating time. When the capacity of the pit is 60 cells, the pit is full most of the time. This is the same as giving preference to removing soaked ingots all the time. That is why, the waiting time for soaked ingots is less. The output didn't increase by 1/6th (220 ingots) because of insufficient arriving ingots. So a 15 percent increase in the capacity is not required. Probably 10 or 12 percent increase is sufficient, Table 10.

Model 3/(8, 12): in run No. 12, the average number of ingots arriving on a train is 8 instead of 7. The capacity of the pit is not sufficient, Table 11. In this type of model no cold ingots are created in the system. All the arriving ingots are waiting to be charged into the soaking pit, even though they are cold. But 117 ingots are charged with the heating time equal to 8 hours. These can be considered as cold ingots. The average heating time of an ingot has increased by 25 percent, because of charging ingots with 8 hours heating time and because of the increase in waiting time. When eight ingots are arriving per train, the capacity of the pit should be increased by at least 5 percent.

Even though the theoretical output per hour (number of cells in the soaking pit/average heating time of an ingot) of the pit is 20.2 ingots, when 7 ingots are arriving per train, it has fallen to 16.3 ingots with 8 ingots per train. This shows when the pit is overloaded, the soaking pit output that can be achieved decreases.

TABLE 10

OUTPUT SUMMARY FOR MODEL 5/22, 26)

Model Run	Capacity of the pit, cells	Output of ingots per hr.	Arriving ingots waiting for crane		Waiting time for soaked ingots, min.		Heating time, hrs.
			Max.	at the end of 100 hrs.	Mean	Max.	
M5/22	60.00	13.78	165.00	80.00	1.15	12.38	3.89
M5/26	70.00	14.94	65.00	0.00	2.01	31.00	3.66

TABLE 11

OUTPUT SUMMARY FOR MODEL 3/(8, 12)

Model Run	Ingots arriving in half an hr.	Output of ingots per hr.	Arriving ingots waiting		Empty cells	Ingots having 8 hrs. heating time	Heating time hrs.	Theoretical output per hr. ingots
			Mean	Max.				
M3/8	7.00	13.55	2.01	16.00	18.61	0.00	2.93	20.4
M3/12	8.00	14.59	42.00	109.00	5.20	117.00	3.68	16.3

5-4-6. The effect of change in the track time variation.

The variation in the track time has a normal distribution. This directly effects the heating time of an ingot. Heating time of an ingot is calculated by adding the track time to the waiting time of an ingot. When the track time increases by 0.5 hours, the heating time curve after the optimal track time is utilized. Model 3/(14, 13). The ideal capacity that can be achieved has fallen down to 12.2 ingot/hour from 20.8 ingots per hour. Model 3/(14, 17): when the variation in the track time is reduced by using a standard deviation of 0.1 hour instead of 0.3 hours, the ideal capacity has increased by 2 ingots/hour. When the ingots arrive 0.2 hours ahead of the optimal time, the ideal capacity has increased by 0.5 ingots per hour only. Model 3/(15, 17). This is because the heating curve is less sensitive at the optimal track time, Table 12. The value of the output variables didn't change when uniform distribution between 0.0 hour and 1.0 hour is assumed instead of normal distribution with a mean of 0.5 hours and a standard deviation of 0.3 hours, Model 6/(30, 31).

5-4-7. The effect of the crane time.

Model 6/(25, 27): in run No. 27, the average crane time is reduced from 1.5 minutes to 1 minute, Table 13. Whenever the ingots are waiting to be charged, or to be drawn, the crane is able to perform its function effectively and quickly. This may be one of the reasons for more variation in the output of ingots per hour and the time between departures of ingots from the system.

When the crane service time is increased from 1.5 minutes to 2.0 minutes, it increased the number of cold ingots created in the system. Model 6/

TABLE 12

OUTPUT SUMMARY FOR MODEL 3/(14, 15, 17, 13)

Model/run	Track time variation, hrs.		Output of ingots per hr.	Theoretical output per hr, ingots
M3/14	0.50	0.30	13.56	20.80
M3/15	0.30	0.10	13.60	23.30
M3/17	0.50	0.10	13.60	22.70
*M3/13	1.00	0.30	11.19	12.20

*The normal distribution has a mean of 0.5 hours. To the value obtained from the normal distribution, 0.5 hours is added.

TABLE 13

OUTPUT SUMMARY FOR MODEL 6/(25, 27)

Model / Run	Average crane time, min.	Output of ingots per hr.		T.B.D	Waiting time in minutes		Heating time, hrs.	Cold ingots created	Cold ingots created
		Mean	Std-dev / Mean	Std-dev / Mean	Arriving ingots	soaked ingots			
M6/25	1.60	13.04	0.36	1.16	9.20	2.12	3.06	210.00	40.00
M6/27	1.10	13.90	0.40	1.42	5.20	1.00	2.96	129.00	46.00

(31, 32). The crane becomes a serious bottleneck. But a smoother output and time between departures is achieved.

5-4-8. Change in the sequence of random numbers.

Changing the random number sequence does not change the essential characteristics of the system. There is a variation in the output of ingots in 100 hours (1354 vs 1280 ingots), Model 3/(8, 16).

Model 4/(37) is run up to 900 hours of simulation. Fig. 23 shows the control chart for the average output of ingots per hour. All points are within the control limits. It can be concluded that the process is under control.

5-5. GENERAL OBSERVATIONS

The frequency distributions of the output variables are shown in Fig. 24 to 31. This program is run on an I.B.M. 360/50. FORTRON IV G level. It takes 13.5 minutes to compile and run for 100 hours of simulation and 25.5 minutes to compile and run for 230 hours of simulation. The compilation time is about 6 minutes.

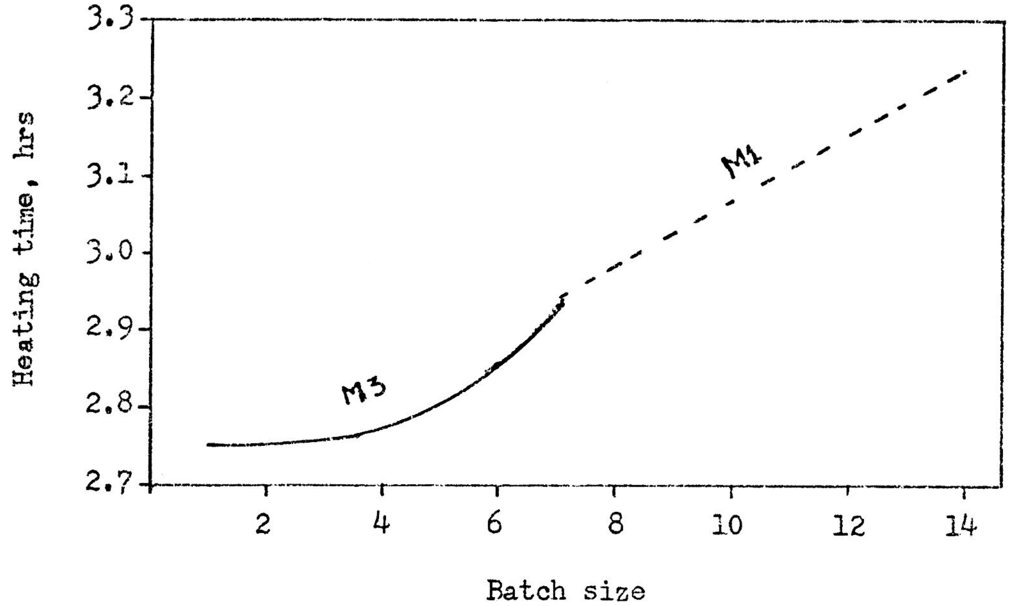

Fig. 22. Relation between heating time and batch size

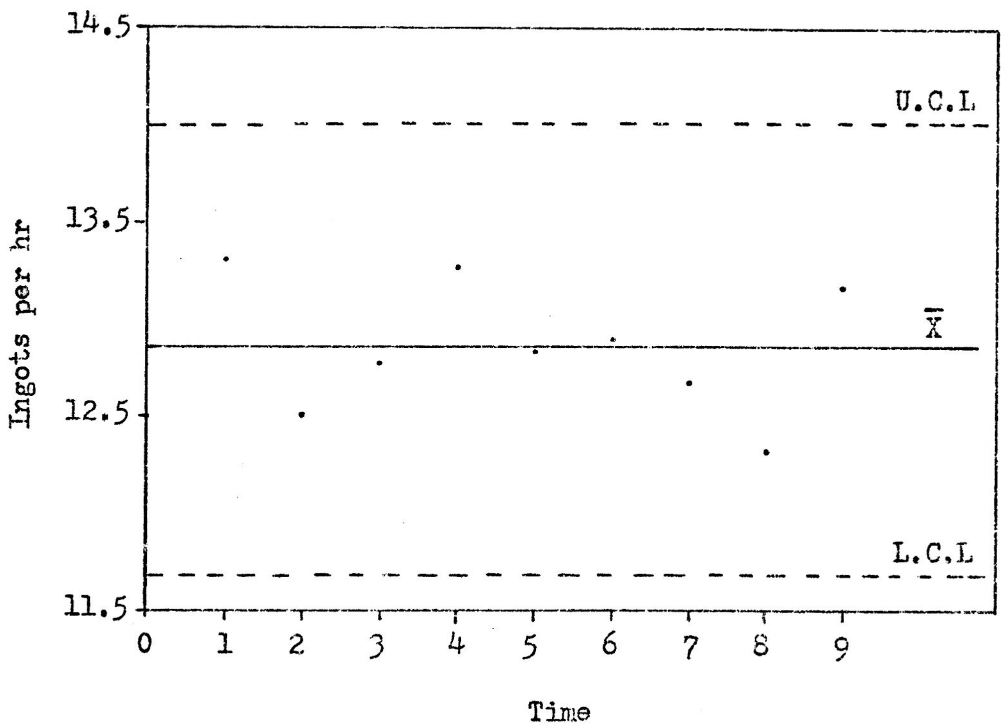

Fig. 23. $\bar{X}$ chart for the average output of ingots

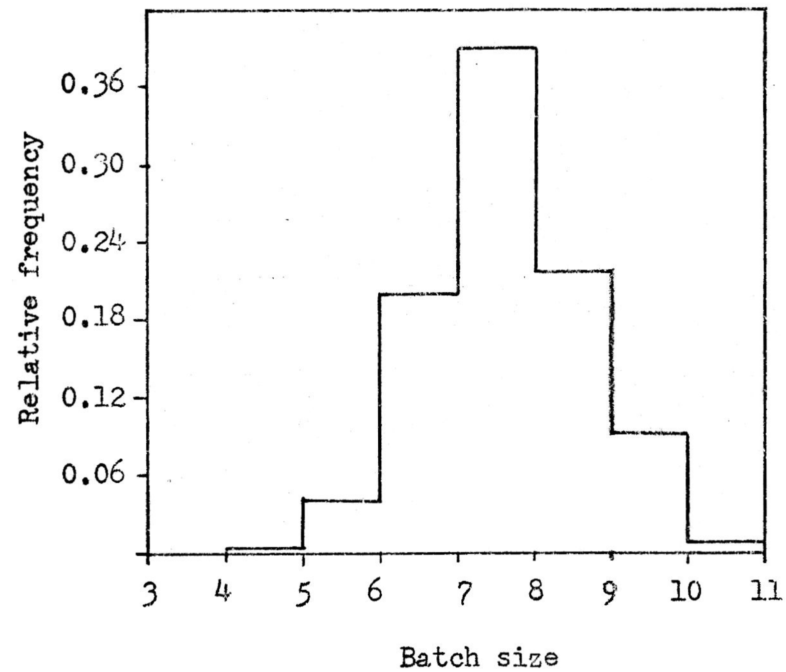

Fig. 24. Distribution of ingots batch size: Model 6/(39)

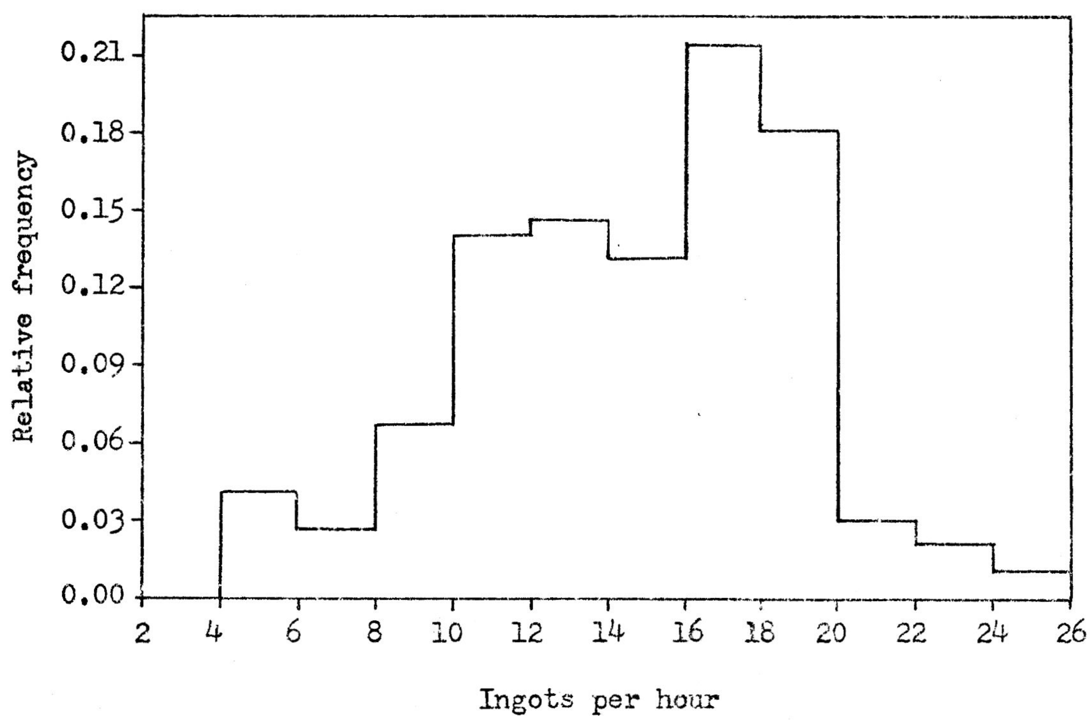

Fig. 25. Distribution of ingots output per hour: Model 6/(39)

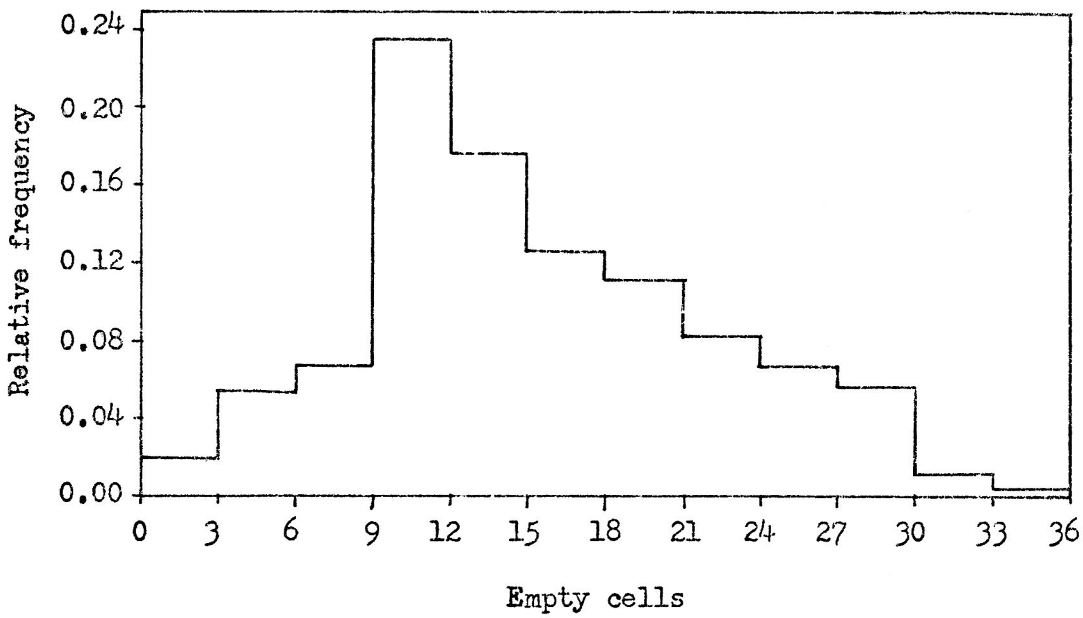

Fig. 26. Distribution of empty cells: Model 6/(39)

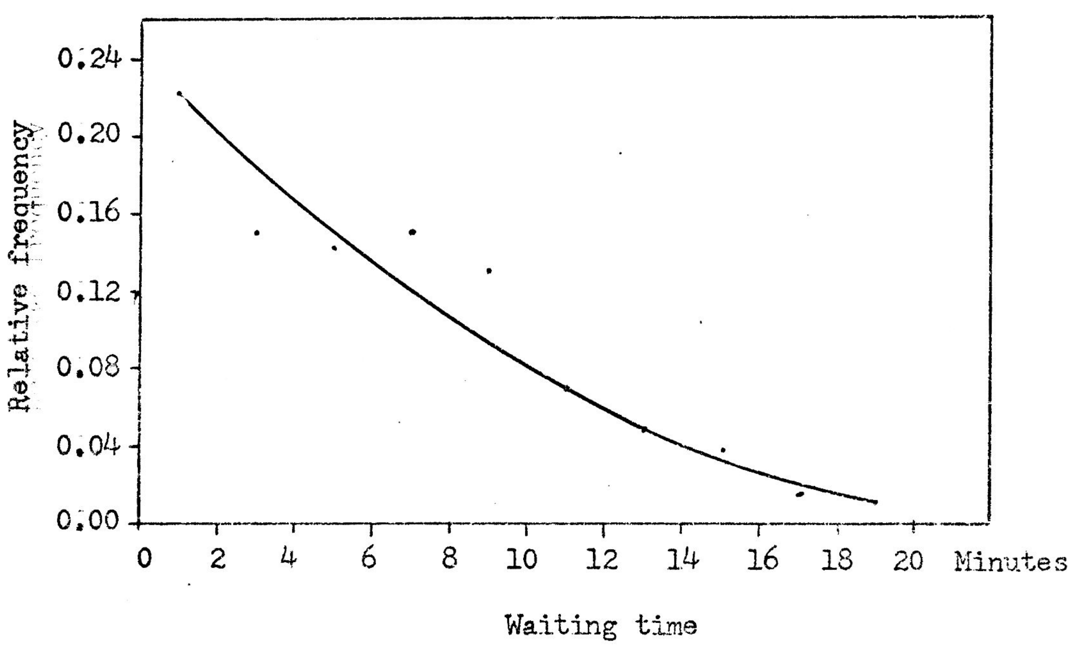

Fig. 27. Distribution of waiting time for arriving ingots: Model 6/(39)

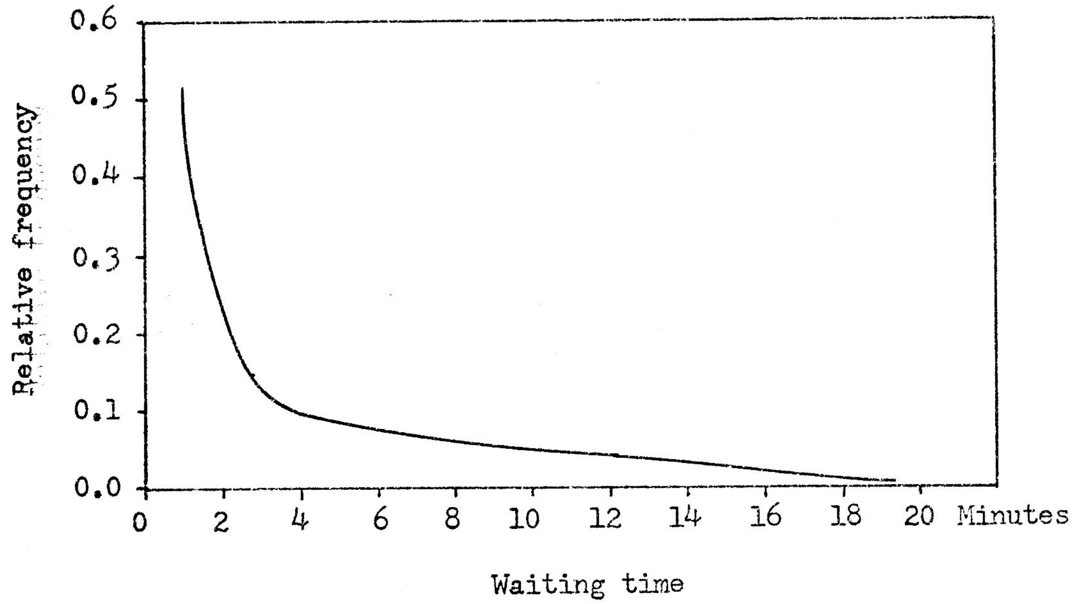

Fig. 28. Distribution of waiting time for soaked ingots: Model 6/(39)

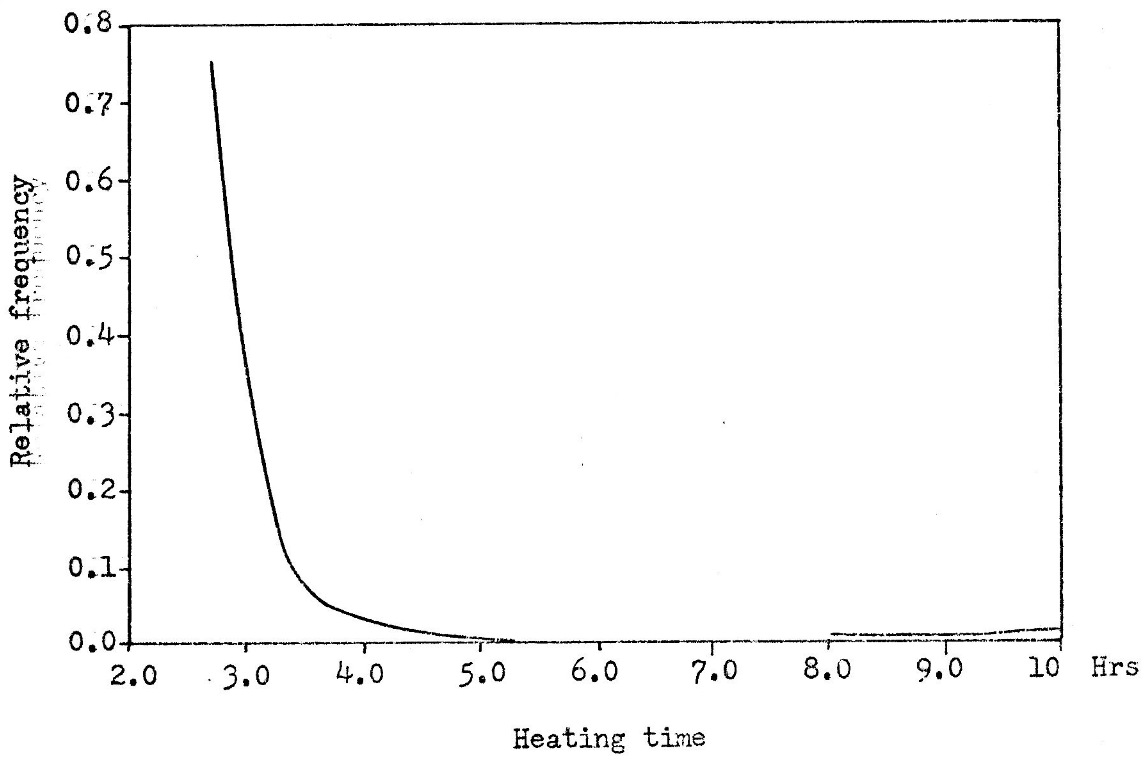

Fig. 29. Distribution of heating time: Model 6/(39)

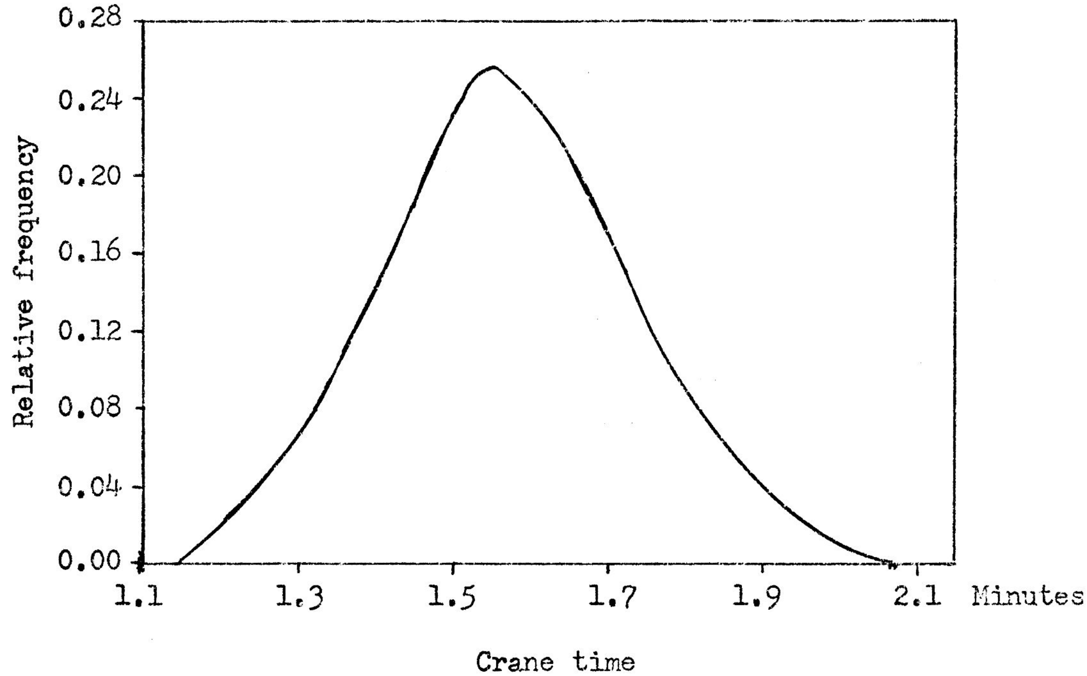

Fig. 30. Distribution of crane times: Model 6/(39)

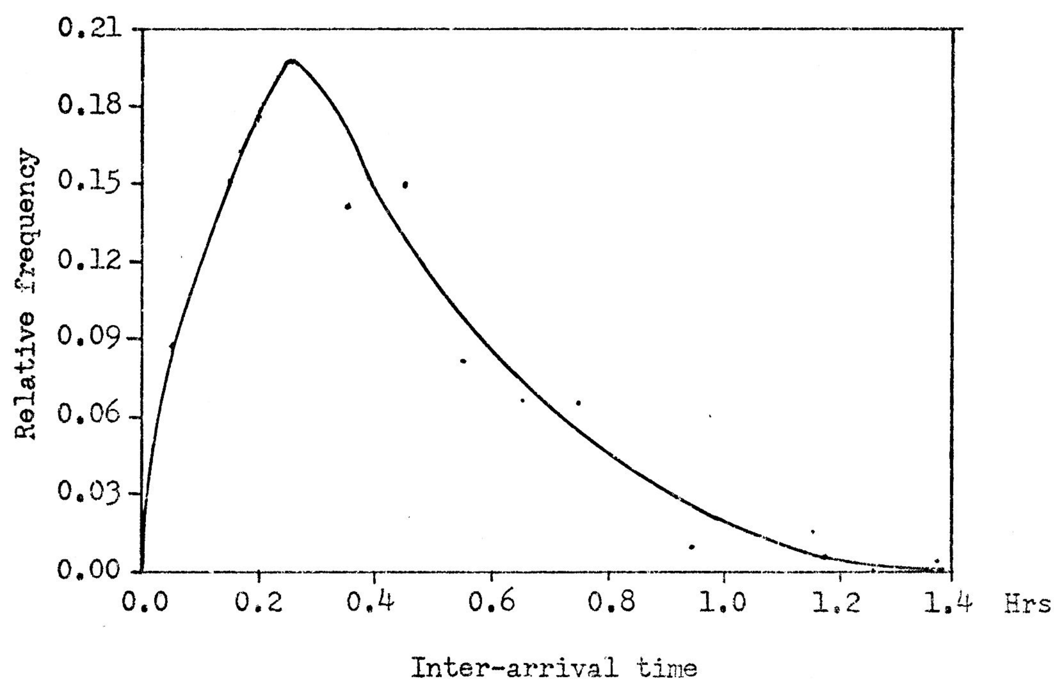

Fig. 31. Distribution of inter-arrival times: Model 6/(39)

CHAPTER 6

CONCLUSIONS

A brief summary of conclusions resulting from this study is presented here.

CAPACITY OF THE PIT

For trains arriving at half hour intervals, 7.75 ingots per train seems to be the best solution under the following conditions:

1. Inter-arrival time has an Erlang 4 distribution.
2. The number of ingots on a train has a normal distribution.
3. The variation in the track time has a normal distribution with a mean of 0.5 hours and a standard deviation of 0.3 hours.
4. The capacity of the pit is 60 cells.
5. FRAC 2 and FRAC 1 are 0.2, and 0.5 respectively.

The criterian used in selecting the capacity of the soaking pit is the number of cold ingots in the system; cold ingots should not build up with time. Then the average output of soaked ingots is equal to the average input of arriving ingots.

Model 4/(37) was run for 900 hours of simulation time. Fig. 23 shows the $\bar{x}$ chart for the average output and the process is under control.

CRANE

There are periods where the crane is utilized 100 percent of the time. The average utilization of the crane is 77 percent. It is one of the controlling factors in the simulation. This effects the waiting time for arriving ingots. One of the possible ways of reducing the crane time is through the movement of the train, when the train arrives at the side of the soaking pit. The train can be indexed in such a way that the ingot to be removed from the train is nearer to the pit.

EMPTY CELLS

The FIFO rule is used for empty cells; that is the cell which was emptied first will service the charging ingot first. Since the crane operation does not consider the geographic location of the empty cell, even the LIFO rule can be used. The time for the to-and-fro motion of the crane is approximated.

DECISION RULES

Decision rules, especially pertaining to the crane operation, seem to be the limiting factors for the system. The FRAC 2 and FRAC 1 determine the type of crane service. With the increase in the utilization of the pit, the two constants should be decreased. But there is a limit beyond which the effect of the decrease in value is negligible. When the FRAC 1 was decreased from 0.5 to 0.4 in Model 6/(41), the system created 50 percent more cold ingots, which will effect the economy of the soaking pit operation. The exact fraction which gives best results is not determined, since it takes considerable amount of computer time. It is left to the future research. The FRAC 1 ensures that there is sufficient space in the soaking pit for the arriving ingots, by not allowing the cold ingots to be charged. Similarly the drawing of soaked ingots is controlled by FRAC 2, since a definite schedule for drawing of the soaked ingots is not available. On the average 80 percent of the pit is utilized. So there is sufficient space in the pit for charging more ingots. If it is known early that a sufficient number of hot ingots will not arrive in the near future, cold ingots can be charged without the consideration of the number of empty cells.

FUTURE RESEARCH

The effect of drawing soaked ingots according to the rolling requirements and the effect of known future arrival of hot ingots can be investigated. Instead of independent heating control of each cell, the soaking pit can be divided into a number of sections which can accomodate more than one ingot. Then the exact crane service time can be calculated. The operations both on the upstream and the downstream can be included in the study.

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APPENDIX A

DIFFERENT MODELS USED IN THE PROGRAM

Variables	Model 1	Model 2	Model 3	Model 4
1. Attribute on which the arriving ingots are ranked.	Distance from the pit.	Distance from the pit.	Time at which the arriving ingot enters the system.	Time at which the arriving ingot enters the system.
2. Queue discipline for arriving ingots.	FIFO	FIFO	LIFO	LIFO
3. Arriving ingots queue management.	When a train arrives, the waiting ingots are sent to the cold ingot yard. It assumes only one track.	Only one track is assumed; but it can accomodate three trains. If there is sufficient space at the front of the soaking pit, the train will stop at the front of the pit. Otherwise it is placed at the back of the existing train. If there is no space on the track the train is diverted to the cold ingot yard. This model uses a mixture of FIFO and LIFO for the trains.	There is no restriction on the number of tracks for the trains. The trains will stay on the track until they are emptied.	A train can stay for TQ hours on the track. If the waiting time is more than that, it is sent to the cold ingot yard.
4. Cold ingots.	Cold ingots are created on the basis of arriving ingots queue management. They are charged into the soaking pit according to the priority ratio.	Same as in Model 1.	Cold ingots are not created. Even if an ingot becomes cold, it will stay on the track, and is always available for charging.	Same as in Model 1.
5. Attribute on which the soaked ingots are ranked.	The time at which the ingot is ready to be drawn after being heated.	Same as in Model 1.	Same as in Model 1.	Same as in Model 1.
6. Queue discipline for soaked ingots.	FIFO	FIFO	FIFO	FIFO
7. Attribute on which the empty cells are ranked.	Time at which the cell became empty.	Same as in Model 1.	Same as in Model 1.	Same as in Model 1.
8. Queue discipline for empty cells.	FIFO	FIFO	FIFO	FIFO

The above table shows the comparison between Models 1 - 4. Models 5 and 6 are similar to Models 3 and 4, but the statistics are initialised at the end of 5 hours.

APPENDIX B

PROGRAM VARIABLES

PROGRAM VARIABLES

KR	= a variable to specify the state of the crane.
	= 0--the crane is idle.
	= 1--the crane is charging cold ingots.
	= 2--the crane is charging arriving ingots.
	= 3--the crane is drawing soaked ingots.
SX	= Speed of the crane along the pit, 6000'/hr.
SY	= Speed of the crane across the pit, 3000'/hr.
FI	= A constant in the crane service time, 0.01667 hrs.
CT	= Crane service time.
PU	= Productive time for the crane in the periods, HRS.
TCRUT	= Cumulative productive time for the crane.
FRAC 1	= Fraction of the empty pit which decides the charging of arriving ingots or drawing of soaked ingots.
FRAC 2	= Fraction of the empty pit, which decides the charging of an arriving ingot or drawing a cold ingot.
L1	= a variable to specify the heating of a cold ingot or an arriving ingot.
	= 1--for an arriving ingot.
	= 2--for a cold ingot.
NCEL	= Number of cells in the pit, 60.
XD	= Length of the pit, 50'.
YD	= Width of the pit, 30'.
XH	= Distance of the ingot chariot from the pit, 25'.
XC1, XC2	= Maximum and minimum distances of the cold ingot yard from the pit.

LCON	= The minimum distance of the ingot from the pit, 15'.
LDIST	= Distance between two ingots on the train, 5'.

Constants in the heating time curve

TT1 = 0.5 hrs

TT2 = 1.5 hrs

PT1 = 2.5 hrs

A1 = 3.0

A2 = 1.2

C1	= Minimum heating time for a cold ingot, 8 hrs.
C2	= Maximum heating time for a cold ingot, 10 hrs.
X	= Track time of an arriving ingot.
HRS	= A small interval to gather statistics, 1 hr.
DELTA	= A report interval for printing out all the statistics, 100 hrs.
NTRN	= Number of ingots on a train.
NSYS	= Number of soaked ingots produced in the soaking pit.
NINGR	= Number of soaked ingots produced in the interval, HRS.
NREP	= Number of soaked ingots produced in the report interval, DELTA.
NCOLD	= Number of cold ingots created in the system.
NC	= Number of cold ingots charged into the soaking pit.
TLD	= Time of last departure of an ingot from the system, hrs.
T.B.D	= Time between departures of ingots from the system, minutes.
WAITIN	= Waiting time for an arriving ingot, minutes.

THWAIT	= Waiting time for a soaked ingot, minutes.
THEAT	= Heating time for an ingot, hrs.
TQ	= Maximum time the train can wait on the track, 2 hrs.
NT	= Maximum number of trains that can stay on the track, 3.
ER	= Interarrival time for trains.
Model A/(B) MA/B	= This notation is used to specify model type and run number. A is the type of model and B is the run number.

APPENDIX C

BASIC GASP II VARIABLES

The following is an alphabetized list of Basic GASP II variables stored in COMMON. All GASP variables are in COMMON except the array NSET. Dimensioned variables are given in terms of their general subscripted values with Basic GASP II values indicated in the definitions.

ATTRIB (IM)	Buffer storage used for attribute values going into NSET or coming out of NSET. (IM $\leqslant$ 4).
ENQ (NOQ)	Expected number of entries in a file. (NOQ $\leqslant$ 4).
ID	Number of columns of NSET (ID limited only by available storage).
IM	Number of attribute rows in NSET (IM $\leqslant$ 4).
INIT	An indicator. The statements INIT = 1 CALL SET (1, NSET) initializes NSET.
INN (NOQ)	An indicator. If INN (J) = 1, the entries in file J are ordered by row KRANK (J) from lowest value to highest value (FIFO). If INN (J) = 2, the entries in file J are ordered by row KRANK (J) from highest value to lowest value (LIFO). INN (1) = 1. (NOQ $\leqslant$ 4).
JCELLS (NHISTO, MXC)	Storage array for histograms. (NHISTO $\leqslant$ 15, MXC $\leqslant$ 22).
JCLEAR	An indicator to determine if the entire GASP system should be re-initialized prior to performing another simulation. That is, if JCLEAR is less than or equal to 0, TNOW is set equal to TSTART and the simulation is repeated without changing the condition of the simulation. If JCLEAR is greater than 0, the system is initialized prior to repeating a simulation run.
JEVENT	Event code of event to be processed. Also used as a control in subroutine MONTR where if JEVENT = 101, NSET is printed, and if JEVENT = 100, the next event is printed until another event with JEVENT = 100 occurs.

JMONIT	An indicator which if 1 causes each event to be monitored. If 0, no monitoring occurs.
KRANK (NOQ)	KRANK (J) is the attribute row on which file J is ranked. KRANK (1) = 1. (NOQ $\leqslant$ 4).
MAXNQ (NOQ)	MAXNQ (J) is the maximum number of entries in file J (NOQ $\leqslant$ 4).
MFA	A variable which identifies the first column in NSET available for storing an event or entity.
MFE (NOQ)	MFE (J) is the first entry in file J. (NOQ $\leqslant$ 4).
MLC (NOQ)	MLC (J) is the entry in file J to be removed next.
MLE (NOQ)	MLE (J) is the last entry in file J. (NOQ $\leqslant$ 4).
MSTOP	An indicator for specifying method of ending the simulation. MSTOP = 0 an end of simulation event is required in which MSTOP set 0 is required. NORPT can then be set to call SUMARY if desired. MSTOP > 0 simulation ended when TNOW $\geqslant$ TSTOP.
MX	Successor row in array NSET.
MXC	Largest number of cells to be used in any histogram (MXC $\leqslant$ 22).
MXX	Predecessor row in array NSET. MXX = IM + 2.
NCELLS (NHISTO)	NCELLS (J) is the number of cells in histogram J not including end cells (NCELLS (J) $\leqslant$ 20).
NCOLCT	The number of sets of statistics that can be collected in COLECT (NCOLCT $\leqslant$ 10).
NEP	An indicator used in DATAIN for initialization. If NEP = 1, new parameters are read in. If NEP = 0, only NSET, TNOW and

	statistical arrays are initialized.
NHISTO	The number of histograms to be obtained in the simulation (NHISTO $\leq$ 15).
NOQ	The number of files in NSET (NOQ $\leq$ 4).
NORPT	An indicator which is greater than zero causes subroutines SUMARY and OUTPUT to be bypassed. If NORPT = 0, SUMARY and OUTPUT are used.
NOT	An indicator used in DATAIN. NOT = 0 simulation starts from beginning. NOT > 0, a check on NEP is made.
NPRAMS	Number of sets of parameters to be read in. (NPRAMS $\leq$ 20).
NQ (NOQ)	NQ (J) is the number of entries in file J at any given time. (NOQ $\leq$ 4).
NRUN	The number of runs completed.
NRUNS	The number of runs remaining to be completed.
NSET (MXX, ID)	The file (MXX $\leq$ 6, ID limited by available storage).
NSTAT	The number of sets of statistics that can be collected in TMSTAT (NSTAT $\leq$ 10).
OUT	An indicator. If OUT = 1, an entry is to be removed from NSET. If OUT = 0, an entry is to be stored in NSET.
PARAMS (NPRAMS, 4)	Array for storing parameter values to be used in generating random variables (NPRAMS $\leq$ 20).
QTIME (NOQ)	QTIME (J) is the time of the last use of file J. (NOQ $\leq$ 4).
SCALE	A parameter used to multiply "floating point" attributes prior to changing them to fixed point for storage in NSET.
SEED	Initial random number.

SSUMA (NSTAT, J)	Array for storing time statistics (NSTAT $\leq$ 10).
SUMA (NCOLCT, J)	Array for storing statistics based on number of observations (NCOLCT $\leq$ 10).
TNOW	The basic time variable of the simulation.
TSTART	Initial value of TNOW.
TSTOP	Time to end the simulation if simulation is ended on time (MSTOP $>$ 0).

APPENDIX D

SUMMARY OF THE SIMULATION OUTPUT FOR DIFFERENT RUNS

A summary of the simulation output is shown in Table 14. All the runs upto run number 36 are made for 100 hours of simulation time unless otherwise specified. Run numbers 38-41 are made for 230 hours of simulation time. Unless specified, the track time variation is assumed to be normally distributed with a mean of 0.5 hours and a standard deviation of 0.3 hours. The minimum value is 0.0 hour and the maximum in 1.5 hours.

TABLE 14 SUMMARY OF THE SIMULATION OUTPUT FOR DIFFERENT RUNS

SNo	Model/run No.	Inter arrival time: Mean hrs.	Inter arrival time: Distrn	Ingots per train	Frac 2/ Frac 1	Output of ingots per hour: Mean	Output of ingots per hour: σ	T.B.D. minutes: Mean	T.B.D. minutes: σ	Heating time: Mean	Heating time: σ	Ingots waiting, Arriving: Mean	Ingots waiting, Arriving: Max	Ingots waiting, Soaked: Mean	Ingots waiting, Soaked: Max	No. of empty cells: Mean	No. of empty cells: σ	No. of empty cells: Min	No. of empty cells: Max	Cold ingots created	Cold ingots charg-ed	Utilization of the crane, %	Waiting time, minutes, Arriving ingots: Mean	Waiting time, minutes, Arriving ingots: σ	Waiting time, minutes, Arriving ingots: Max	Waiting time, minutes, Soaked ingots: Mean	Waiting time, minutes, Soaked ingots: σ	Waiting time, minutes, Soaked ingots: Max
1	M1/3	1.00	ER-4	15.00	0.20/0.50	14.53	4.07	4.33	4.80	3.24	1.11	4.52	16.00	1.37	13.00	12.94	6.10	0.00	30.00	140.00	28.00	76.50	16.29	11.76	52.98	5.92	8.25	41.32
2	M1/4	0.50	ER-4	7.00	0.20/0.50	13.49	4.50	4.45	5.00	2.94	0.99	1.27	9.00	0.86	8.00	19.09	8.05	0.00	30.00	32.00	32.00	70.20	5.36	4.17	24.00	3.80	4.70	32.20
3	M1/6	0.50	ER-4	7.00	0.40/0.60	13.23	4.43	4.53	4.71	2.92	0.87	1.59	9.00	0.37	7.00	19.00	7.71	0.00	36.00	50.00	18.00	68.60	6.72	5.42	36.94	1.68	2.76	20.44
4	M1/9	1.00	ER-4	14.00	0.20/0.50	13.53	4.72	4.34	5.66	3.23	1.23	3.72	15.00	1.31	14.00	14.32	8.87	0.00	30.00	92.00	44.00	73.19	14.51	11.13	62.12	5.90	8.89	45.10
5	M2/7	0.50	ER-4	7.00	0.20/0.50	13.54	5.01	4.43	5.23	2.92	0.77	1.81	17.00	0.83	8.00	18.30	8.20	0.00	30.00	7.00	7.00	71.40	7.71	10.42	81.00	3.66	4.68	28.10
6	M3/8	0.50	ER-4	7.00	0.40/0.60	13.55	4.73	4.43	4.57	2.93	0.67	2.01	16.00	0.41	8.00	18.61	9.29	0.00	37.00	---	---	71.45	9.01	13.21	136.00	1.92	3.01	24.42
7	M3/12	0.50	ER-4	8.00	0.40/0.60	14.59	5.05	4.01	4.02	3.68	1.69	42.00	109.00	0.30	6.00	5.20	7.47	0.00	21.00	---	---	78.18	58.00	144.00	1654.00	1.13	1.09	7.87
8*	M3/13	0.50	ER-4	7.00	0.40/0.60	11.19	4.10	5.19	4.86	4.91	1.83	76.00	188.00	0.13	4.00	2.75	5.00	0.00	8.00	---	---	60.15	32.00	64.00	533.00	0.72	0.89	6.19
9	M3/14	0.50	ER-4	7.00	0.20/0.60	13.56	5.08	4.31	5.50	2.89	0.63	1.78	17.00	0.81	8.00	18.75	8.60	0.00	40.00	---	---	71.31	7.75	12.00	171.00	3.59	4.58	29.01
10•	M3/15	0.50	ER-4	7.00	0.20/0.60	13.60	4.94	4.31	6.79	2.60	0.38	1.51	16.00	1.22	10.00	22.20	8.09	3.00	40.00	---	---	71.00	6.00	11.00	156.00	5.41	6.38	40.00
11▣	M3/17	0.50	ER-4	7.00	0.20/0.60	13.60	4.82	4.29	6.09	2.64	0.43	1.58	16.00	1.29	9.00	21.70	8.25	0.00	40.00	---	---	72.00	6.87	11.78	166.00	5.20	6.10	42.60
12⊙	M3/16	0.50	ER-4	7.00	0.40/0.60	12.80	4.52	4.57	4.89	2.94	0.72	2.00	18.00	0.41	6.00	22.20	7.19	0.00	38.00	---	---	67.90	9.41	14.00	113.00	1.87	2.73	18.65
13	M3/18	0.33	ER-4	4.67	0.40/0.60	12.54	4.03	4.67	4.86	2.79	0.43	0.92	13.00	0.30	5.00	23.30	6.87	0.00	39.00	---	---	64.90	4.31	6.00	80.00	1.47	2.21	15.00
14	M3/19	0.25	ER-4	3.50	0.40/0.60	11.92	3.73	4.90	4.61	2.76	0.38	0.49	8.00	0.25	4.00	25.20	5.68	4.00	38.00	---	---	61.50	2.30	2.87	28.70	1.28	1.82	11.79
15	M4/20	0.50	ER-4	7.00	0.40/0.60	13.21	4.31	4.41	4.61	2.94	0.94	1.71	12.00	0.37	6.00	19.20	6.92	3.00	36.00	53.00	24.00	69.90	7.10	6.00	48.00	1.70	2.50	15.00
16	M5/21	0.50	ER-4	7.00	0.40/0.60	13.92	4.24	4.30	4.30	2.98	0.77	2.40	18.00	0.27	5.00	18.10	8.82	0.00	35.00	---	---	71.00	10.70	16.00	198.01	1.20	1.60	12.60
17	M5/22	0.50	ER-1	7.00	0.40/0.60	13.78	4.89	4.55	4.62	3.89	1.80	71.00	165.00	0.26	6.00	6.14	8.73	0.00	34.00	---	---	69.95	110.00	356.00	2687.00	1.15	1.36	12.38
18#	M5/26	0.50	ER-1	7.00	0.40/0.60	14.94	5.33	4.00	4.61	3.66	1.64	13.10	62.00	0.50	10.00	16.01	14.33	0.00	49.00	---	---	78.00	54.00	175.00	1877.00	2.01	3.12	31.00
19	M6/23	0.07	ER-1	1.00	0.40/0.60	13.43	3.17	4.65	3.94	2.75	0.34	0.21	5.00	0.22	5.00	22.30	5.31	4.00	32.00	112.00	0.00	64.60	0.84	2.31	40.00	1.01	1.41	12.30
20	M6/24	0.50	ER-8	7.00	0.40/0.60	13.13	3.36	4.77	4.68	2.86	0.67	1.50	9.00	0.39	6.00	21.40	6.30	1.00	36.00	8.00	8.00	65.30	6.30	5.06	38.00	1.81	2.82	19.00
21	M6/25	0.50	ER-1	7.00	0.40/0.60	13.04	4.73	4.59	5.34	3.06	1.10	2.20	22.00	0.40	8.00	19.90	8.66	0.00	36.00	210.00	40.00	69.21	9.20	12.81	124.00	2.12	4.14	40.00
22$	M6/27	0.50	ER-1	7.00	0.40/0.60	13.92	6.40	4.28	6.10	2.96	1.07	1.30	15.00	0.20	7.00	18.80	9.85	0.00	36.00	129.00	46.00	51.00	5.20	9.00	125.00	1.00	1.91	14.00
23+	M6/32	0.50	ER-4	7.00	0.40/0.60	12.57	2.88	4.78	4.52	3.00	0.84	3.10	27.00	0.82	8.00	21.60	5.80	2.00	36.00	135.00	10.00	84.00	11.10	15.50	173.00	4.10	5.70	36.00
24	M6/31	0.50	ER-4	7.00	0.40/0.60	13.61	3.65	4.42	4.57	2.94	0.03	1.60	11.00	0.37	6.00	19.60	7.20	3.00	36.00	52.00	26.00	69.00	7.00	5.60	44.10	1.71	2.72	21.00
25	M6/28	0.50	ER-1	7.00	0.55/0.60	12.83	4.90	4.67	5.55	3.12	1.26	2.30	24.00	0.21	6.00	19.94	9.26	0.00	36.00	243.00	52.00	68.00	9.50	13.00	122.00	1.30	1.80	14.90
26▲	M6/30	0.50	ER-4	7.00	0.40/0.60	13.65	3.60	4.40	4.55	2.96	0.90	1.61	12.00	0.40	6.00	19.30	8.21	0.00	36.00	50.00	26.00	69.00	7.10	6.50	76.00	1.64	2.64	23.00
27■	M6/29	0.50	UNIF	7.00	0.40/0.60	12.58	3.59	4.78	4.99	2.88	0.74	1.30	16.00	0.40	8.00	23.20	6.12	2.00	36.00	44.00	10.00	64.00	6.20	6.70	78.00	2.10	3.45	23.00
28	M6/34	0.50	CONS	7.00	0.40/0.60	13.03	2.03	4.60	4.30	2.83	0.46	1.31	9.00	0.40	5.00	22.80	2.50	13.00	30.00	0.00	0.00	66.85	6.40	4.30	24.00	1.90	2.20	10.80
29	M6/35	0.50	ER-4	7.00	0.40/0.50	13.82	3.63	4.34	4.44	3.04	1.20	1.61	10.00	0.32	6.00	17.60	6.99	0.00	37.00	50.00	50.00	70.80	7.10	5.80	67.00	1.50	2.40	22.00
30	M6/36	0.50	ER-4	9.00	0.40/0.60	15.81	4.09	3.80	3.60	2.98	0.68	4.50	28.00	0.30	6.00	12.50	7.50	0.00	35.00	224.00	0.00	81.80	11.00	11.00	167.00	1.30	1.70	17.00
31●	M4/37	0.50	ER-4	7.00	0.40/0.60	12.84	3.85	4.57	4.87	2.88	0.71	1.41	14.00	0.40	8.00	21.90	6.70	0.00	36.00	451.00	194.00	66.10	6.40	5.10	30.00	1.80	2.80	23.00
32	M6/38	0.50	ER-4	7.50	0.20/0.50	13.98	4.41	4.29	5.30	3.06	1.25	1.47	16.00	1.05	11.00	16.38	6.70	0.00	37.00	94.00	94.00	73.25	6.37	5.98	76.84	5.12	6.19	32.33
33	M6/39	0.50	ER-4	7.75	0.20/0.50	14.28	4.18	4.19	4.89	3.05	1.21	1.56	16.00	1.05	11.00	15.68	6.47	0.00	35.00	112.00	83.00	75.04	6.83	6.53	80.32	4.65	6.25	36.68
34	M6/40	0.50	ER-4	7.88	0.20/0.50	14.45	4.05	4.15	4.85	3.05	1.16	1.82	21.00	0.98	11.00	15.10	6.32	0.00	35.00	118.00	66.00	75.95	7.57	6.85	97.51	4.47	5.88	35.24
35	M6/41	0.50	ER-4	7.88	0.20/0.40	14.60	4.37	4.11	4.51	3.23	1.54	2.07	25.00	1.00	11.00	12.46	6.02	0.00	35.00	173.00	147.00	76.82	8.19	8.30	80.02	4.38	5.87	34.70

* It stopped at 81 hours because of too many arriving ingots waiting for the crane. In this run the track time is increased by 0.5 hours for all the trains.

? The track time variation has a mean of 0.3 hours and a standard deviation of 0.1 hours.

⊡ The track time variation has a mean of 0.5 hours and a standard deviation of 0.1 hours.

⊙ All the random numbers have been changed.

The capacity of the soaking pit is increased to 70 cells.

$ Constant time of crane is reduced from 1.0 minute to 0.5 minutes.

+ Constant time of crane is increased to 1.5 minutes from 1.0 minute.

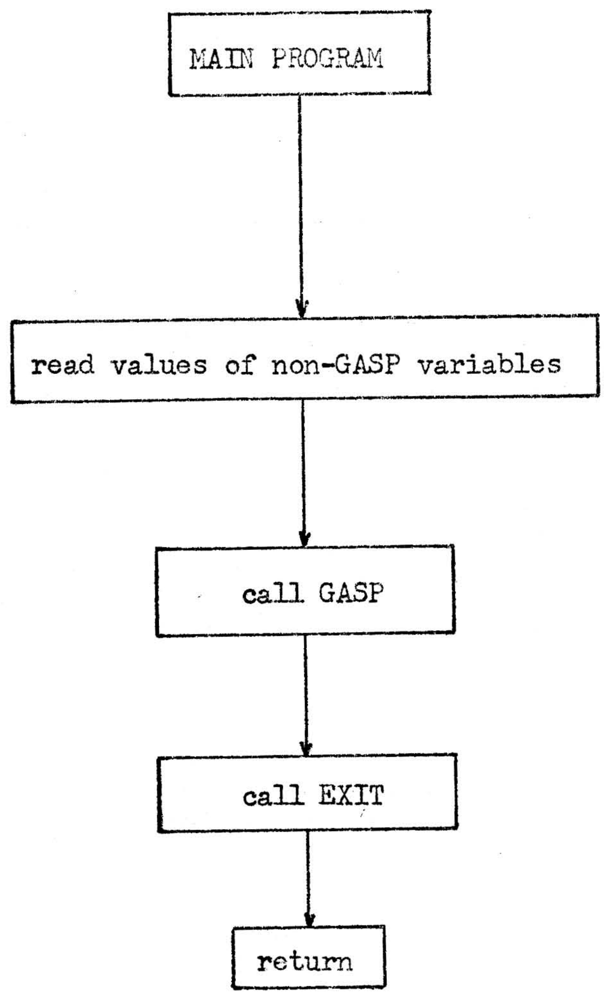
△ Track time variation has a uniform distribution between 0.0 hour and 1.0 hour.

⊠ Inter arrival time of trains have a uniform distribution between 0.1 hour and 0.9 hour.

⊗ It was run upto 900.0 hours.

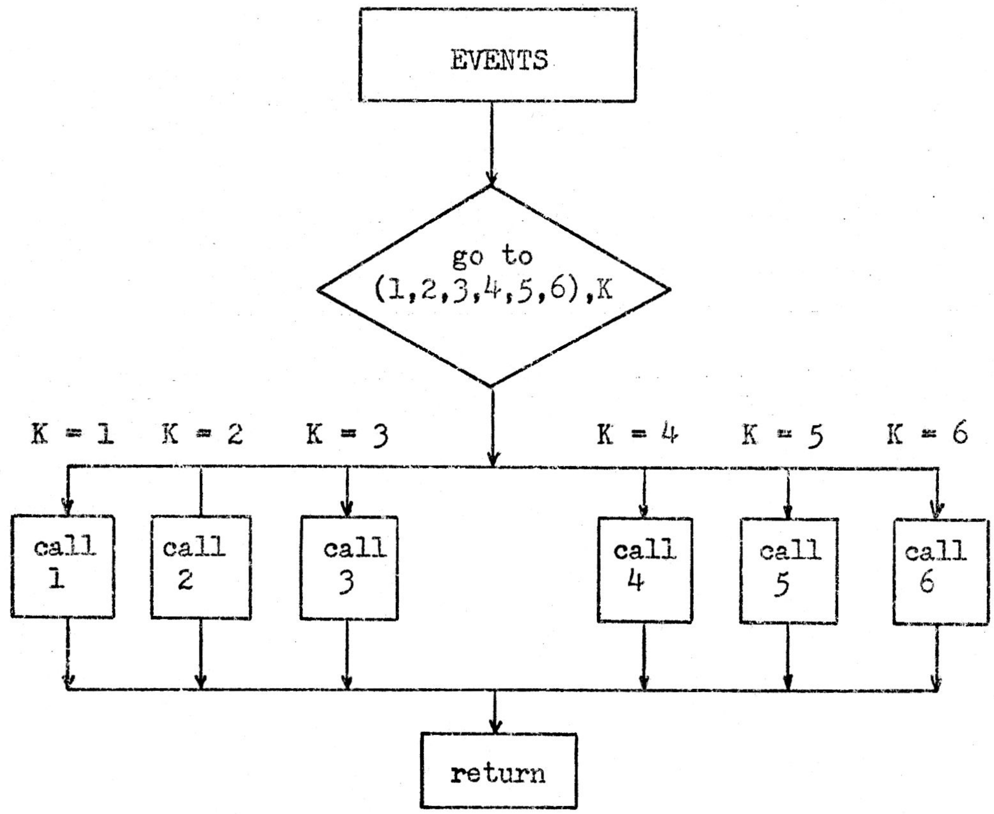
APPENDIX E

FLOW CHARTS



Model 1 - 6

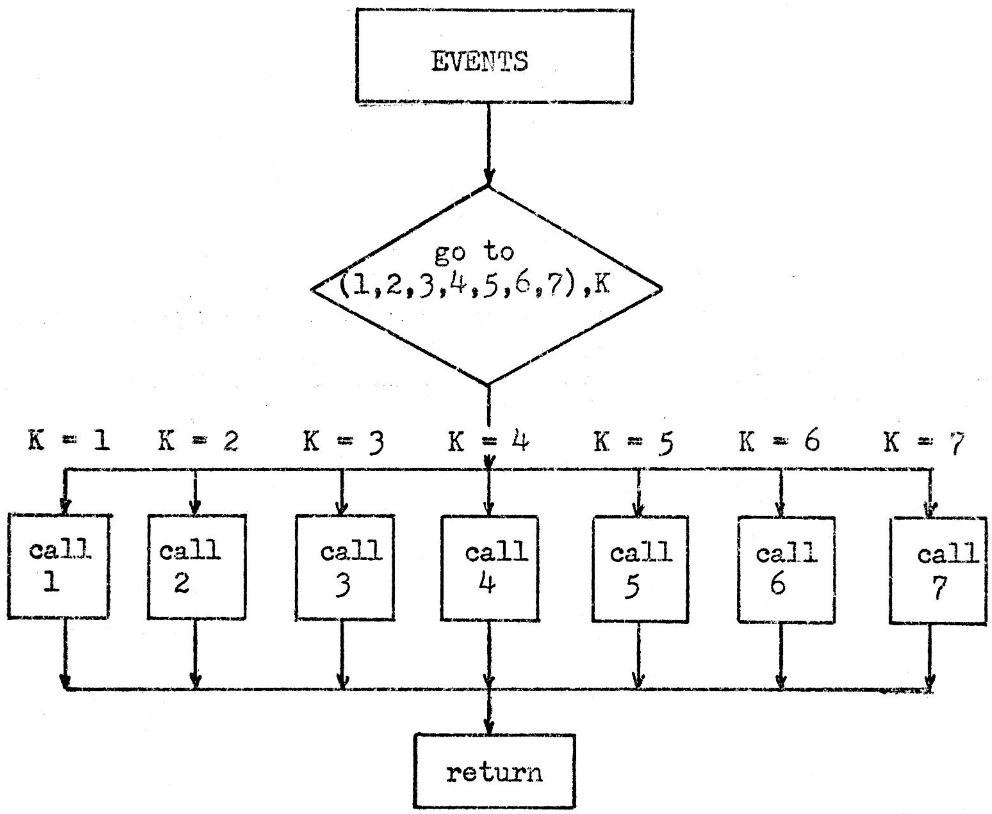
Fig. 32. Main program for soaking pit simulation



1 - ARIVL
2 - EHEAT
3 - ECRANE
4 - HREP
5 - REPORT
6 - COMPL

Models 1 - 3 and 5

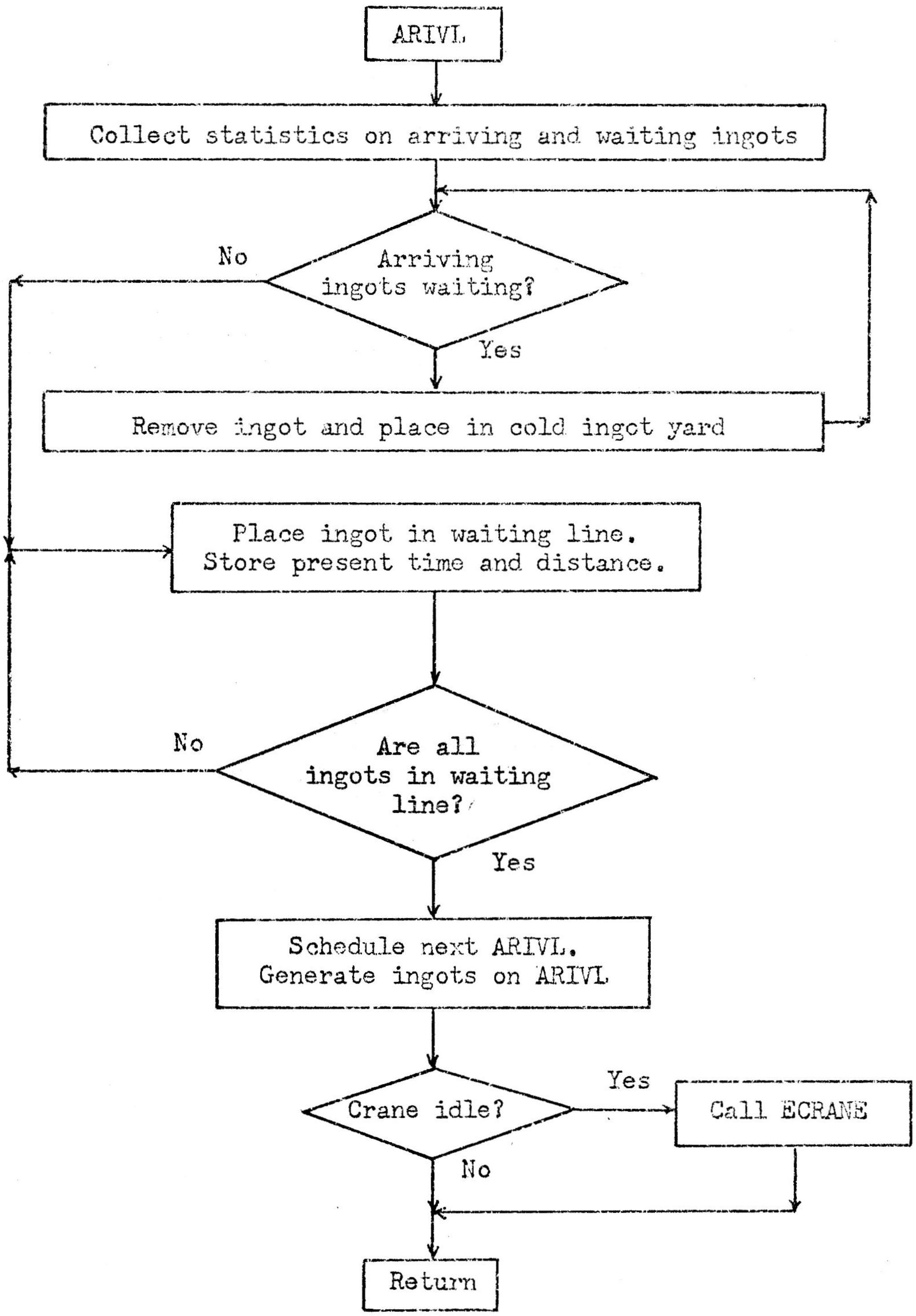
Fig. 33. Subroutine EVENTS



1 - ARIVL
2 - EHEAT
3 - ECRANE
4 - HREP
5 - REPORT
6 - COMPL
7 - INST

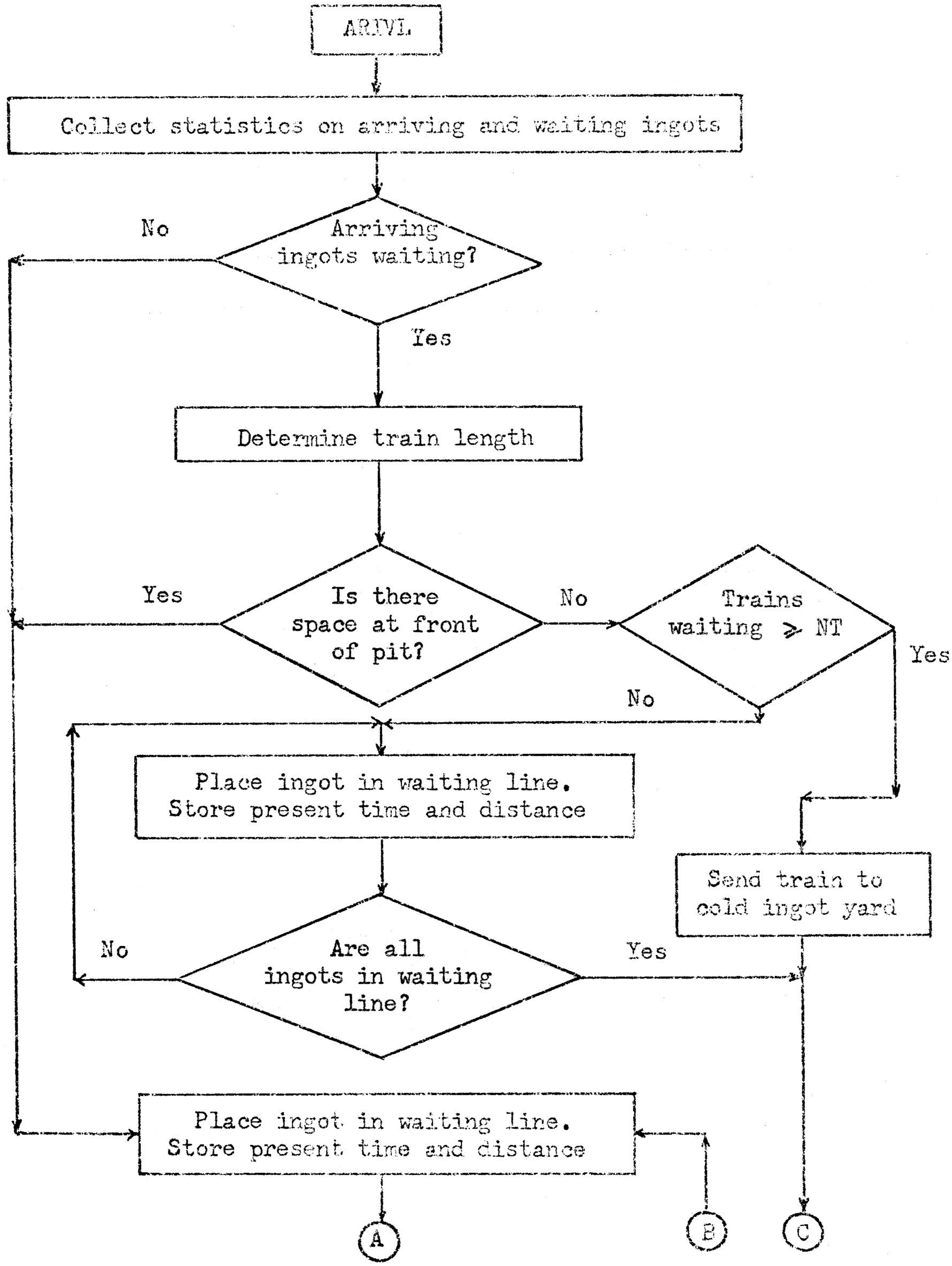
Models 4 and 6

Fig. 34. Subroutine EVENTS



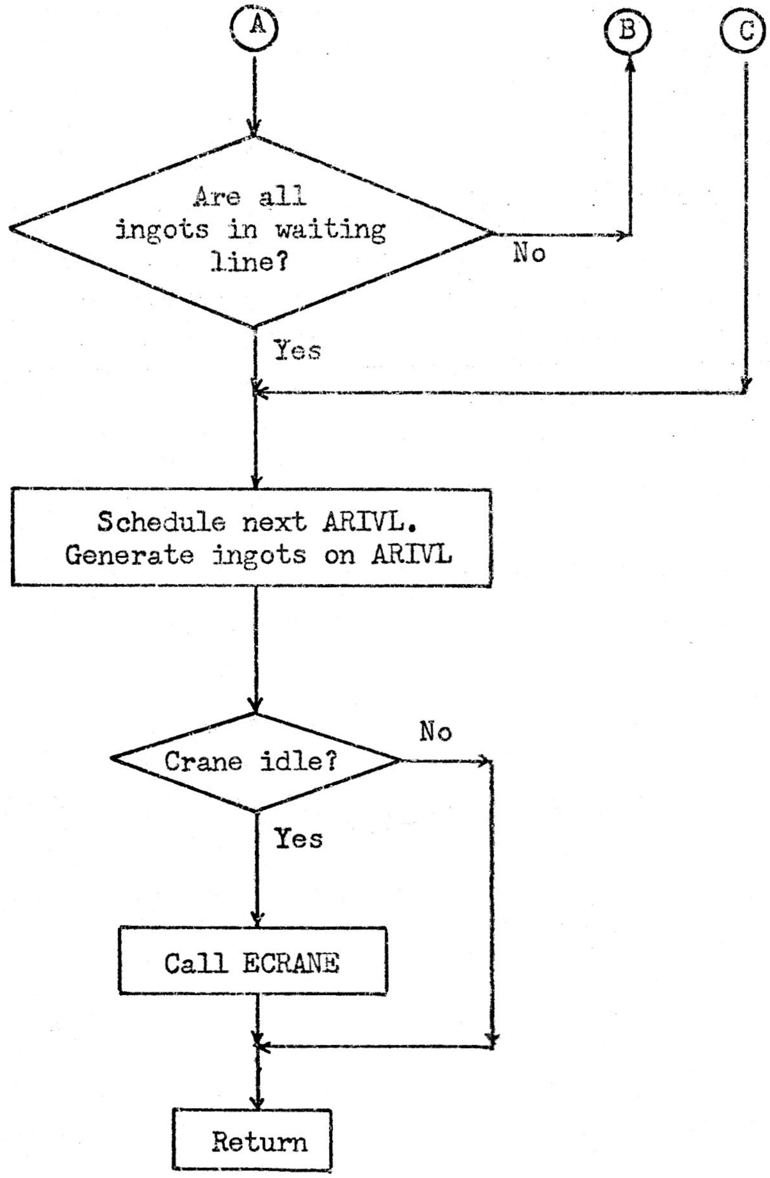
Model 1

Fig. 35. Flow chart of the event ARIVL



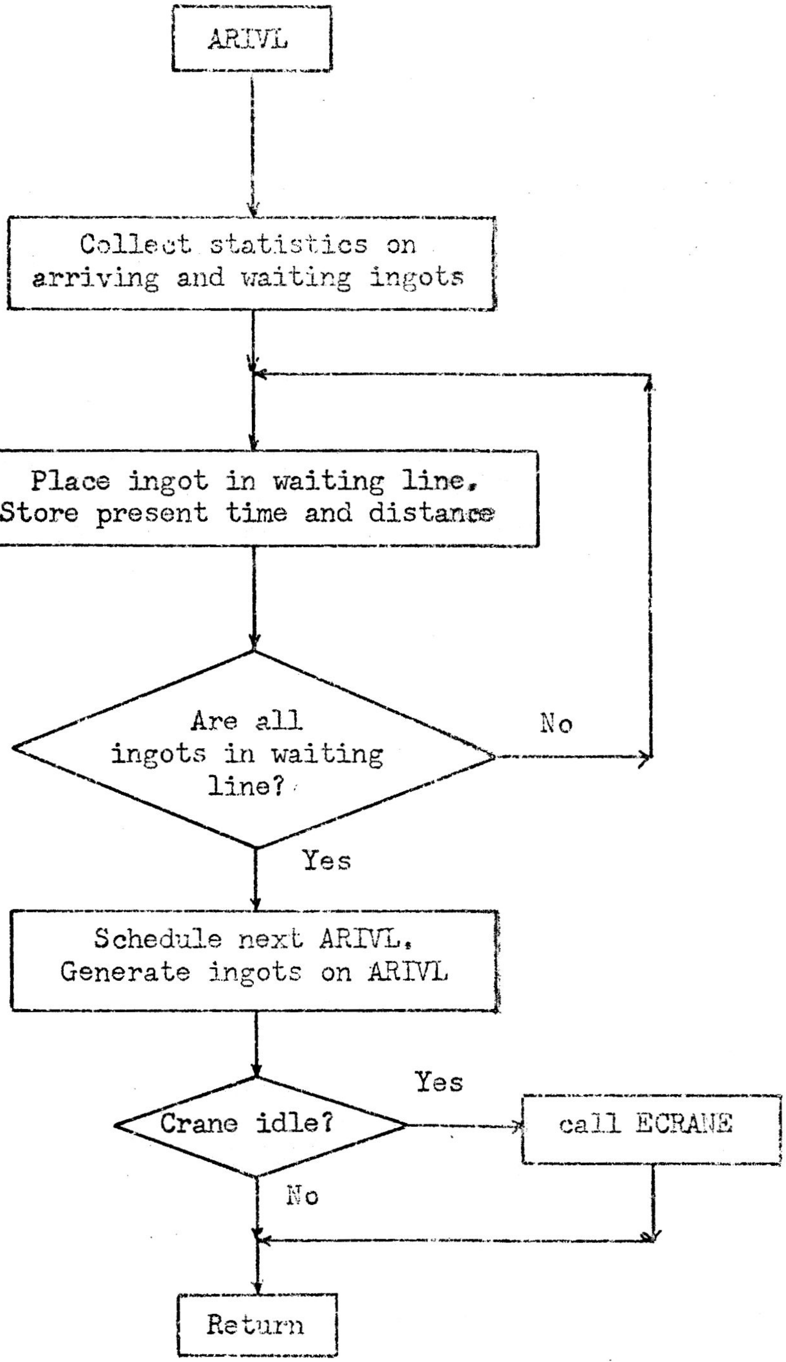
Model 2

Fig. 36. Flow chart of the event ARIVL



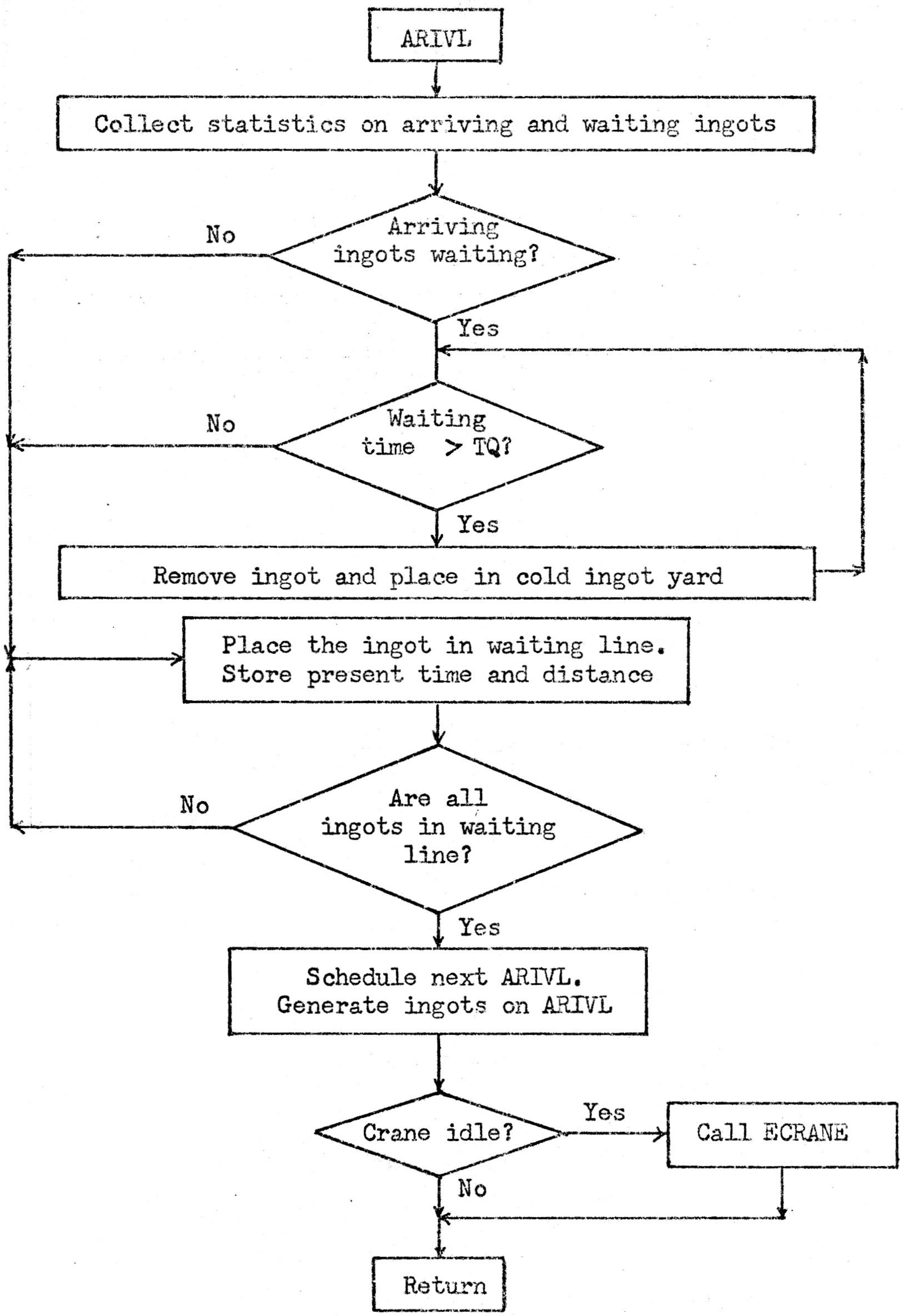
Model 2

Fig. 36. Flow chart of the event ARIVL (cont'd)



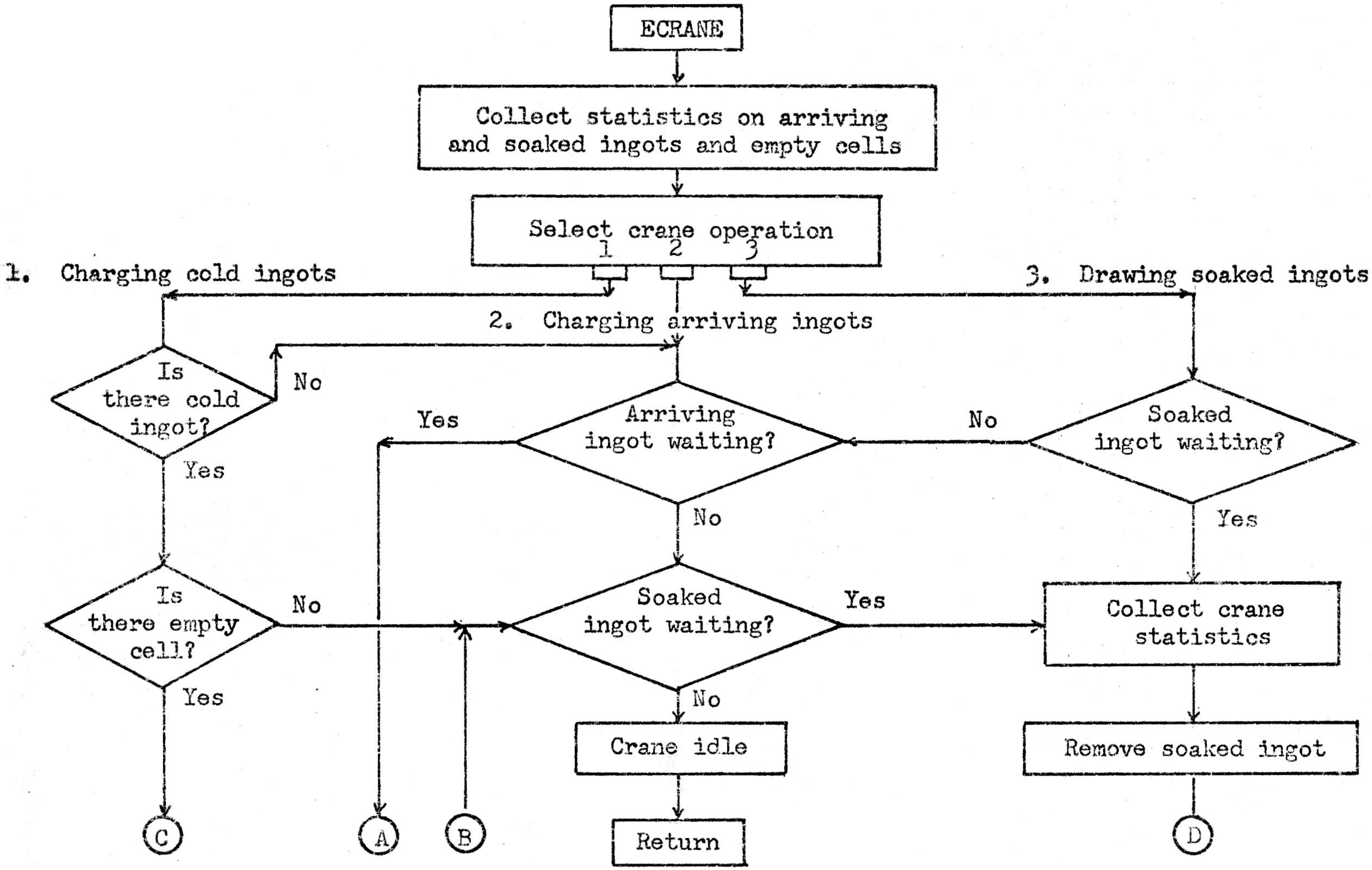
Models 3 and 5

Fig. 37. Flow chart of the event ARIVL



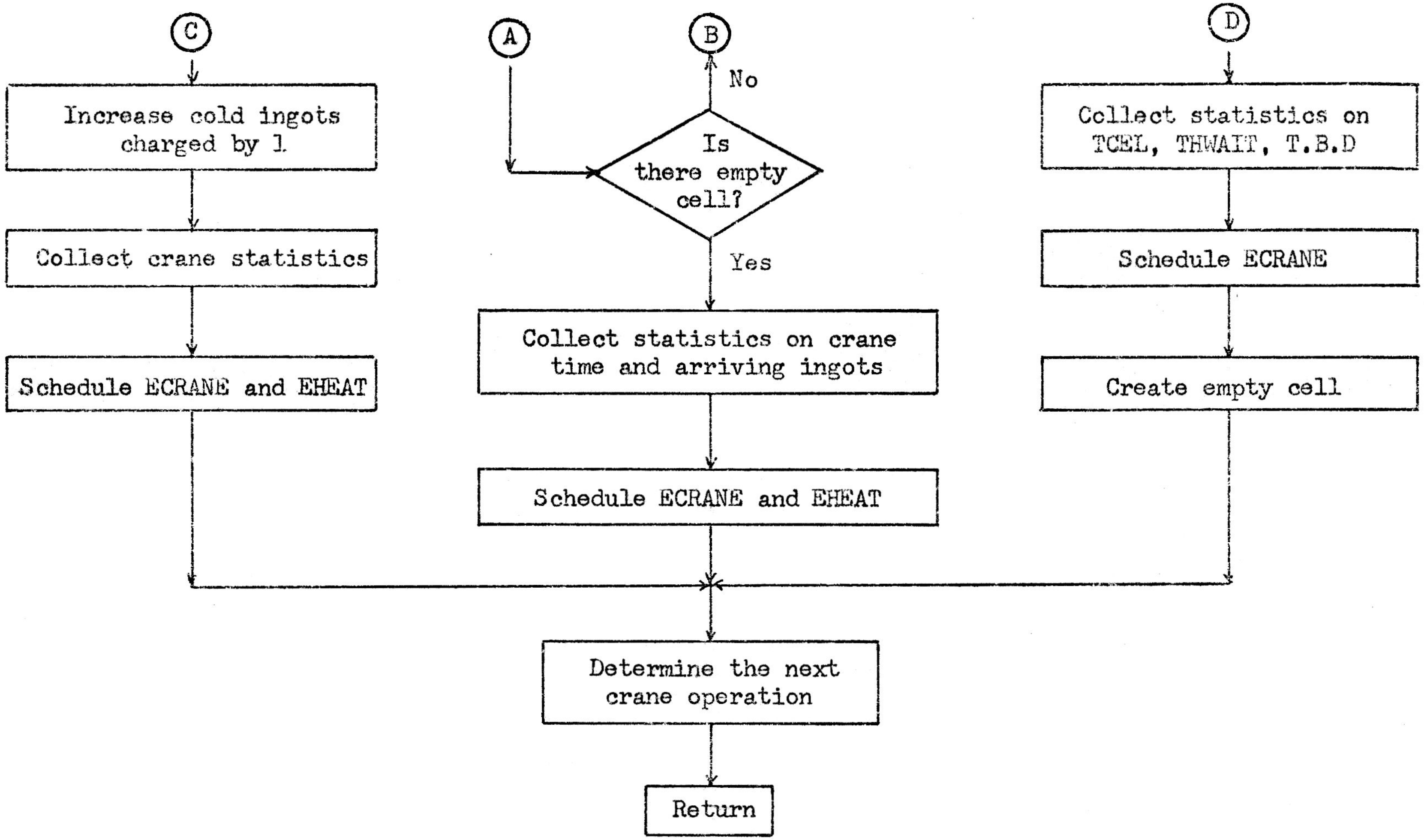
Models 4 and 6

Fig. 38. Flow chart of the event ARIVL



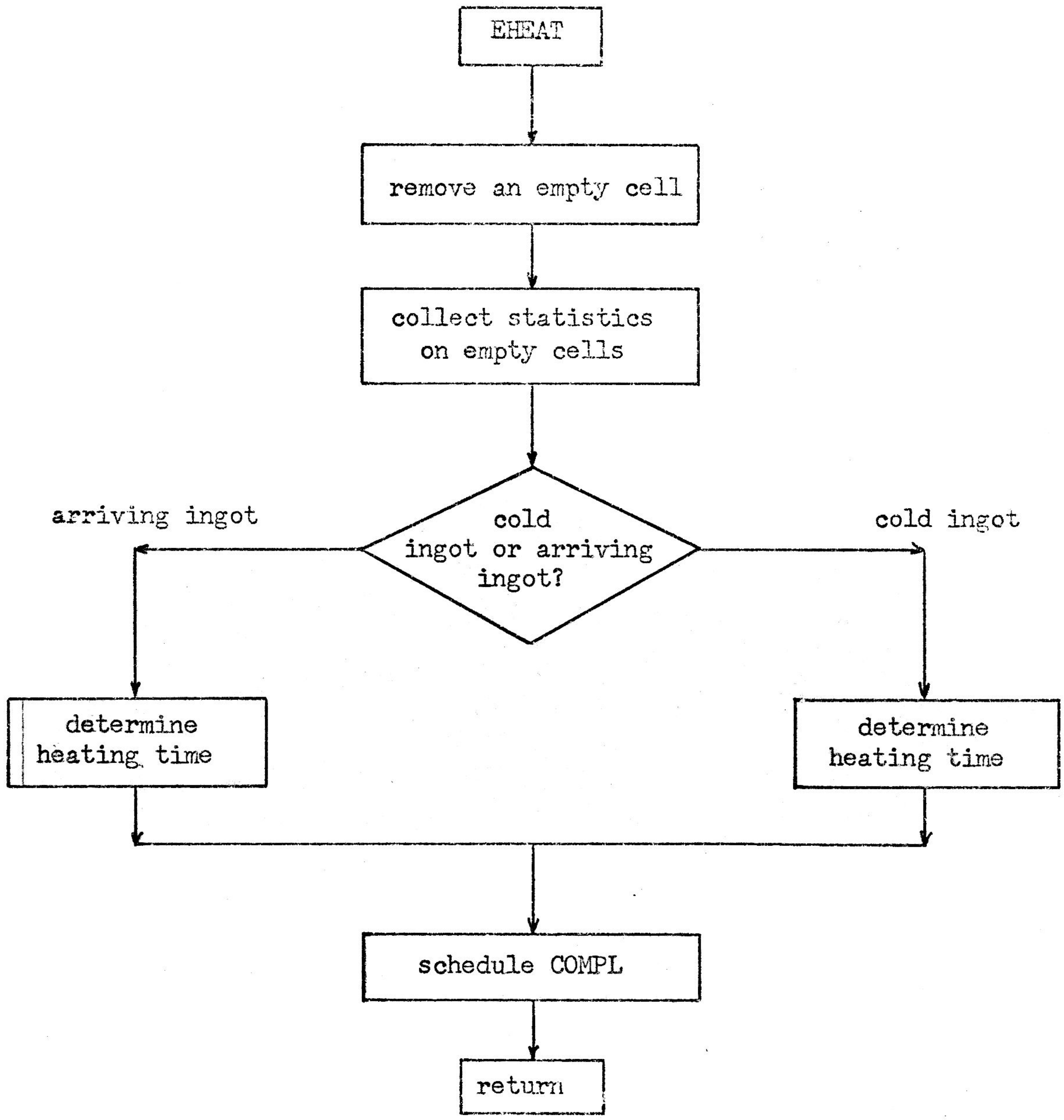
Models 1 - 6

Fig. 39. Flow chart of the event ECRANE



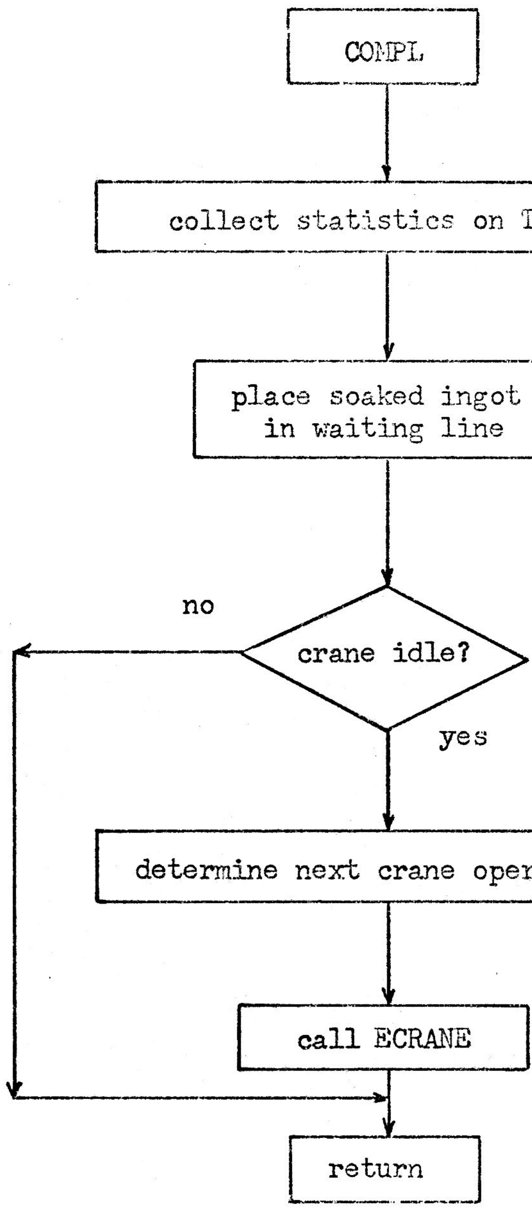
Models 1 - 6

Fig. 39. Flow chart of the event ECRANE (cont'd)



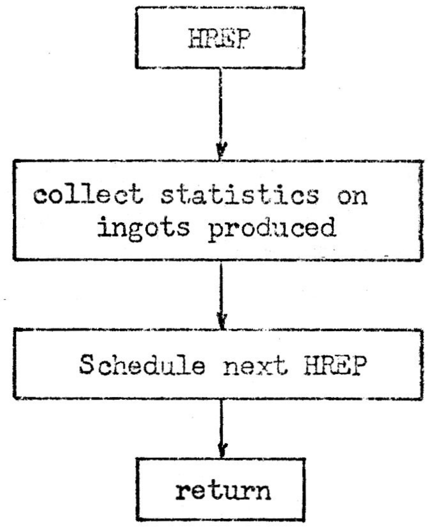
Model 1 - 6

Fig. 40. Flow chart of the event EHEAT



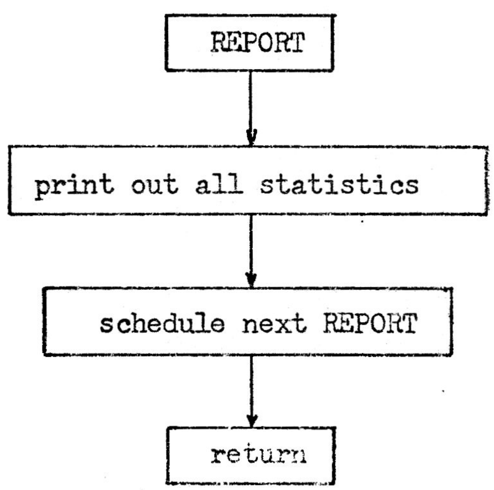
Model 1 - 6

Fig. 41. Flow chart of the event COMPL



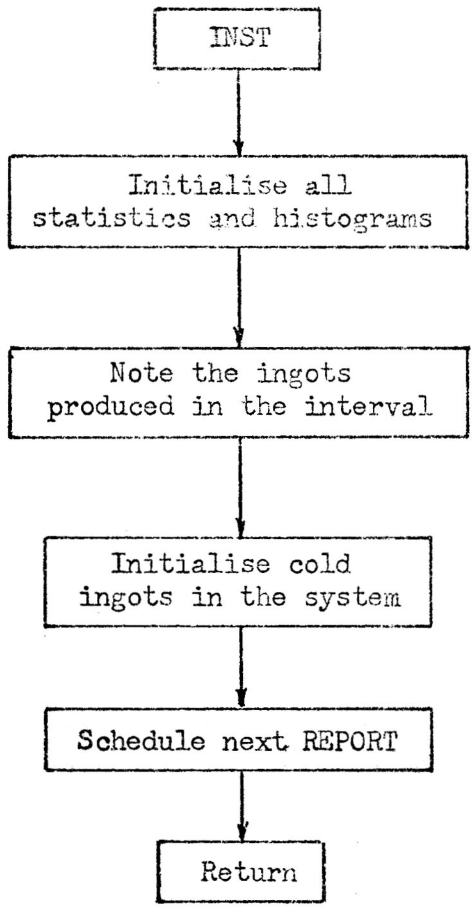
Model 1 - 6

Fig. 42. Flow chart of the event HREP



Model 1 - 6

Fig. 43. Flow chart of the event REPORT



Model 1 - 6

Fig. 44. Flow chart of the event INST

APPENDIX F

PROGRAM

```
C**** MAIN PROGRAM
C
      COMMCN ID,IM,INIT,JEVENT,JMONIT,MFA,MSTOP,MX,MXC,NCOLCT,NHISTO,NCQ
     1,NORPT,NOT,NPRAMS,NRUN,NRUNS,NSTAT,OUT,SCALE,NSEED,TNOW,TSTART,TST
     2OP,MXX
      COMMCN ATTRIB(4),ENQ(4),INN(4),JCELLS(15,22),KRANK(4),MAXNQ(4),MFE
     1(4),MLC(4),MLE(4),NCELLS(15),NQ(4),PARAMS(20,4),QTIME(4),SSUMA(10,
     25),SUMA(10,5),IX(8)
      COMMCN NCEL,FRAC1,FRAC2,NT,SX,SY,F1,XD,YD,XH,XC1,XC2,LCON,LDIST,TT
     11,TT2,PT1,A1,A2,C1,C2,HRS,DELTA
      COMMCN TBD,TLD,NSYS,NTRN,TEMPTY,WAITIN,THEAT,NCOLD,TCRUT,NINGR,NRE
     1P,KR,TCEL,CT,PU,TEL,TX,TY,LD,NC,TQ,ND,RED
      DIMENSION NSET(6,150)
      READ 10,NCEL,FRAC1,FRAC2,SX,SY,F1,XD,YD,XH,XC1,XC2,LCON,LDIST,TT1,
     1TT2,PT1,A1,A2,C1,C2,HRS,DELTA
   10 FORMAT(I5,2F5.2/2F8.1,F10.6,5F5.0,2I4/7F6.2/2F6.0)
      TLD=C.
      CT=0.C
      TCRUT=0.
      PU=0.
      NC=0
      RED=HRS
      TX=0.C
      ND=0
      NSYS=0
      NCOLC=0
      NINGR=0
      NREP=C
      KR=0
      PRINT 11,NCEL,FRAC2,FRAC1,SX,SY,F1,XD
   11 FORMAT(1H0,40X,'  NCEL =',I5/1H0,40X,' FRAC2 =',F5.2/1H0,40X,' FRA
     1C1 =',F5.2/1H0,40X,'    SX =',F8.0/1H0,41X,'    SY =',F8.0/1H0,40X,
     2'    F1 =',F10.6/1H0,40X,'    XD =',F5.0)
   12 FORMAT(1H0,40X,'    YD =',F5.0/1H0,40X,'    XH =',F5.0/1H0,40X,'
     1 XC1 =',F5.0/1H0,40X,'   XC2 =',F5.0/1H0,40X,'  LCON =',I3/1H0,40X
     2,'  LDIST =',I3)
      PRINT 12,YD,XH,XC1,XC2,LCON,LDIST
   13 FORMAT(1H0,40X,'   TT1 =',F6.2/1H0,40X,'   TT2 =',F6.2/1H0,40X,'
     1 PT1 =',F6.2/1H0,40X,'    A1 =',F6.2/1H0,40X,'    A2 =',F6.2)
      PRINT 13,TT1,TT2,PT1,A1,A2
   14 FORMAT(1H0,40X,'    C1 =',F6.2/1H0,40X,'    C2 =',F6.2/1H0,40X,'
     1 HRS =',F6.2/1H0,40X,' DELTA =',F6.0)
      PRINT 14,C1,C2,HRS,DELTA
   15 FORMAT(F8.2)
      READ 15,TQ
   16 FORMAT('    MAX. TIME THE TRAIN CAN WAIT =',F8.2/)
      PRINT 16,TQ
      CALL GASP(NSET)
      CALL EXIT
      END
```

```
      SUBRCUTINE EVENTS(K,NSET)
      COMMCN ID,IM,INIT,JEVENT,JMONIT,MFA,MSTOP,MX,MXC,NCOLCT,NHISTO,NOQ
     1,NORPT,NOT,NPRAMS,NRUN,NRUNS,NSTAT,OUT,SCALE,NSEED,TNOW,TSTART,TST
     2OP,MXX
      COMMCN ATTRIB(4),ENQ(4),INN(4),JCELLS(15,22),KRANK(4),MAXNQ(4),MFE
     1(4),MLC(4),MLE(4),NCELLS(15),NQ(4),PARAMS(20,4),QTIME(4),SSUMA(10,
     25),SUMA(10,5),IX(8)
      COMMCN NCEL,FRAC1,FRAC2,NT,SX,SY,F1,XD,YD,XH,XC1,XC2,LCON,LDIST,TT
     11,TT2,PT1,A1,A2,C1,C2,HRS,DELTA
      COMMCN TBD,TLD,NSYS,NTRN,TEMPTY,WAITIN,THEAT,NCOLD,TCRUT,NINGR,NRE
     1P,KR,TCEL,CT,PU,TEL,TX,TY,LD,NC,TQ,ND,RED
      DIMENSION NSET(6,1)
      GO TC (1,2,3,4,5,6,7),K
    1 CALL ARIVL(NSET)
      RETURN
    2 CALL EHEAT(NSET)
      RETURN
    3 CALL ECRANE(NSET)
      RETURN
    4 CALL HREP(NSET)
      RETURN
    5 CALL REPORT(NSET)
      RETURN
    6 CALL COMPL(NSET)
      RETURN
    7 CALL INST(NSET)
      RETURN
      END
```

Model 1

```
      SUBROUTINE ARIVL(NSET)
      COMMCN ID,IM,INIT,JEVENT,JMONIT,MFA,MSTOP,MX,MXC,NCOLCT,NHISTO,NOQ
     1,NORPT,NOT,NPRAMS,NRUN,NRUNS,NSTAT,OUT,SCALE,NSEED,TNOW,TSTART,TST
     2OP,MXX
      COMMCN ATTRIB(4),ENQ(4),INN(4),JCELLS(15,22),KRANK(4),MAXNQ(4),MFE
     1(4),MLC(4),MLE(4),NCELLS(15),NQ(4),PARAMS(20,4),QTIME(4),SSUMA(10,
     25),SUMA(10,5),IX(8)
      COMMCN NCEL,FRAC1,FRAC2,NT,SX,SY,F1,XD,YD,XH,XC1,XC2,LCON,LDIST,TT
     11,TT2,PT1,A1,A2,C1,C2,HRS,DELTA
      COMMCN TBD,TLD,NSYS,NTRN,TEMPTY,WAITIN,THEAT,NCOLD,TCRUT,NINGR,NRE
     1P,KR,TCEL,CT,PU,TEL,TX,TY,LD,NC,TQ,ND,RED
      DIMENSION NSET(6,1)
      ST=ATTRIB(3)
      I4=ATTRIB(4)
      NTRN=ATTRIB(4)
C
C**** COLLECT STATISTICS ON NQ(2) AND NTRN
C
      CALL HISTOG(FLOAT(NTRN),0.0,1.0,9)
      CALL TMSTAT(FLOAT(NQ(2)),TNOW,2,NSET)
C
C**** CHECK FOR ARRIVING INGOTS WAITING TO BE CHARGED
C
      IF(NQ(2))19,20,21
   19 CALL ERROR(40,NSET)
C
C**** REMOVE THE INGOT AND PLACE IT IN COLD INGOT YARD
C
   21 MFE2=MFE(2)
      CALL REMOVE(MFE2,2,NSET)
      NCOLD=NCOLD+1
      IF(NQ(2).GT.0)GO TO 21
C
C**** PLACE THE ARIVL IN FILE2; STORE TNOW AND DISTANCE FROM PIT
C
   20 I2=0
   25 ATTRIB(1)=LCON+I2*LDIST
      ATTRIB(2)=0
      ATTRIB(3)=ST
      ATTRIB(4)=0
      CALL FILEM(2,NSET)
      I2=I2+1
C
C**** CHECK WHETHER THE ARIVL WAS FILED IN FILE 2
C
      IF(I2.LT.I4)GO TO 25
      ER=ERLANG(4,2)
      CALL HISTOG(ER,.0,0.1,5)
      CALL COLECT(ER,8,NSET)
C
```

```
C**** SCHEDULE NEXT ARRIVAL
C
      TIME=TNOW+ER
C
C**** GENERATE THE NO. OF INGOTS ON THE TRAIN
C
      NN=RNORML(5,1)
C
C**** FILE THE ARIVL INTO THE EVENT FILE
C
      ATTRIB(1)=TIME
      ATTRIB(2)=1.0
      ATTRIB(3)=TIME
      ATTRIB(4)=NN
      CALL FILEM(1,NSET)
C
C**** CHECK WHETHER THE CRANE IS IDLE
C
      IF(KR)30,40,50
   30 CALL ERROR(41,NSET)
   50 RETURN
   40 KR=2
      CALL ECRANE(NSET)
      RETURN
      END
```

Model 2

```
      SUBROUTINE ARIVL(NSET)
      COMMON ID,IM,INIT,JEVENT,JMONIT,MFA,MSTOP,MX,MXC,NCOLCT,NHISTO,NOQ
     1,NORPT,NOT,NPRAMS,NRUN,NRUNS,NSTAT,OUT,SCALE,NSEED,TNOW,TSTART,TST
     2OP,MXX
      COMMON ATTRIB(4),ENQ(4),INN(4),JCELLS(15,22),KRANK(4),MAXNQ(4),MFE
     1(4),MLC(4),MLE(4),NCELLS(15),NQ(4),PARAMS(20,4),QTIME(4),SSUMA(10,
     25),SUMA(10,5),IX(8)
      COMMON NCEL,FRAC1,FRAC2,NT,SX,SY,F1,XD,YD,XH,XC1,XC2,LCON,LDIST,TT
     11,TT2,PT1,A1,A2,C1,C2,HRS,DELTA
      COMMON TBD,TLD,NSYS,NTRN,TEMPTY,WAITIN,THEAT,NCOLD,TCRUT,NINGR,NRE
     1P,KR,TCEL,CT,PU,TEL,TX,TY,LD,NC,TQ,ND,RED
      DIMENSION NSET(6,1)
      ST=ATTRIB(3)
      I4=ATTRIB(4)
      NTRN=ATTRIB(4)
C
C**** COLLECT STATISTICS ON NQ(2) AND NTRN
C
      CALL HISTOG(FLOAT(NTRN),0.0,1.0,9)
      CALL TMSTAT(FLOAT(NQ(2)),TNOW,2,NSET)
C
C**** CHECK FOR ARRIVING INGOTS WAITING TO BE CHARGED
C
      IF(NQ(2))19,20,21
   19 CALL ERROR(40,NSET)
   21 LF=LCON+NTRN*LDIST
C
C**** CHECK FOR SPACE AT THE FRONT OF THE PIT
C
      IF(LD-LF)60,60,20
   60 MLE2=MLE(2)
      CALL REMOVE(MLE2,2,NSET)
      LG=ATTRIB(1)
      CALL FILEM(2,NSET)
      LK=(LCON+IFIX(PARAMS(1,3))*LDIST)*NT
C
C**** CHECK FOR SPACE AT THE BACK OF THE PIT
C
      IF(LG+LF-LK)61,61,90
   90 NCOLD=NCOLD+NTRN
      GO TO 80
   61 I3=0
   70 ATTRIB(1)=LG+LCON+I3*LDIST
      ATTRIB(2)=0.0
      ATTRIB(3)=ST
      ATTRIB(4)=0.0
      CALL FILEM(2,NSET)
      I3=I3+1
      IF(I3.LT.I4) GO TO 70
      GO TO 80
```

```
C
C**** PLACE THE ARIVL IN FILE2; STORE TNOW AND DISTANCE FROM PIT
C
   20 I2=0
   25 ATTRIB(1)=LCCN+I2*LDIST
      ATTRIB(2)=0
      ATTRIB(3)=ST
      ATTRIB(4)=0
      CALL FILEM(2,NSET)
      I2=I2+1
C
C**** CHECK WHETHER THE ARIVL WAS FILED IN FILE 2
C
      IF(I2.LT.I4)GO TO 25
   80 ER=ERLANG(4,2)
      CALL COLECT(ER,8,NSET)
      CALL HISTOG(ER,.0,0.1,5)
C
C**** SCHEDULE NEXT ARRIVAL
C
      TIME=TNOW+ER
C
C**** GENERATE THE NO. OF INGOTS ON THE TRAIN
C
      NN=RNORML(5,1)
C
C**** FILE THE ARIVL INTO THE EVENT FILE
C
      ATTRIB(1)=TIME
      ATTRIB(2)=1.0
      ATTRIB(3)=TIME
      ATTRIB(4)=NN
      CALL FILEM(1,NSET)
C
C**** CHECK WHETHER THE CRANE IS IDLE
C
      IF(KR)30,40,50
   30 CALL ERROR(41,NSET)
   50 RETURN
   40 KR=2
      CALL ECRANE(NSET)
      RETURN
      END
```

Model 3 and 5

```
      SUBROUTINE ARIVL(NSET)
      COMMON ID,IM,INIT,JEVENT,JMONIT,MFA,MSTOP,MX,MXC,NCOLCT,NHISTO,NOQ
     1,NORPT,NOT,NPRAMS,NRUN,NRUNS,NSTAT,OUT,SCALE,NSEED,TNOW,TSTART,TST
     2OP,MXX
      COMMON ATTRIB(4),ENQ(4),INN(4),JCELLS(15,22),KRANK(4),MAXNQ(4),MFE
     1(4),MLC(4),MLE(4),NCELLS(15),NQ(4),PARAMS(20,4),QTIME(4),SSUMA(10,
     25),SUMA(10,5),IX(8)
      COMMON NCEL,FRAC1,FRAC2,NT,SX,SY,F1,XD,YD,XH,XC1,XC2,LCON,LDIST,TT
     11,TT2,PT1,A1,A2,C1,C2,HRS,DELTA
      COMMON TBD,TLD,NSYS,NTRN,TEMPTY,WAITIN,THEAT,NCOLD,TCRUT,NINGR,NRE
     1P,KR,TCEL,CT,PU,TEL,TX,TY,LD,NC,TQ,ND,RED
      DIMENSION NSET(6,1)
      ST=ATTRIB(3)
      I4=ATTRIB(4)
      NTRN=ATTRIB(4)
C
C**** COLLECT STATISTICS ON NQ(2) AND NTRN
C
      CALL HISTOG(FLOAT(NTRN),0.0,1.0,9)
      CALL TMSTAT(FLOAT(NQ(2)),TNOW,2,NSET)
      I2=I4
   25 ATTRIB(1)=LCON+I2*LDIST
      ATTRIB(2)=0
      ATTRIB(3)=ST
      ATTRIB(4)=0
      CALL FILEM(2,NSET)
      I2=I2-1
C
C**** CHECK WHETHER THE ARIVL WAS FILED IN FILE 2
C
      IF(I2.GT.0) GO TO 25
      ER=ERLANG(4,2)
      CALL HISTOG(ER,.0,0.1,5)
      CALL COLECT(ER,8,NSET)
C
C**** SCHEDULE NEXT ARRIVAL
C
      TIME=TNOW+ER
C
C**** GENERATE THE NO. OF INGOTS ON THE TRAIN
C
      NN=RNORML(5,1)
C
C**** FILE THE ARIVL INTO THE EVENT FILE
C
      ATTRIB(1)=TIME
      ATTRIB(2)=1.0
      ATTRIB(3)=TIME
      ATTRIB(4)=NN
      CALL FILEM(1,NSET)
```

```
C
C**** CHECK WHETHER THE CRANE IS IDLE
C
      IF(KR)30,40,50
   30 CALL ERROR(41,NSET)
   50 RETURN
   40 KR=2
      CALL ECRANE(NSET)
      RETURN
      END
```

```
      SUBROUTINE ARIVL(NSET)
      COMMON ID,IM,INIT,JEVENT,JMONIT,MFA,MSTOP,MX,MXC,NCOLCT,NHISTO,NOQ
     1,NORPT,NOT,NPRAMS,NRUN,NRUNS,NSTAT,OUT,SCALE,NSEED,TNOW,TSTART,TST
     2OP,MXX
      COMMON ATTRIB(4),ENQ(4),INN(4),JCELLS(15,22),KRANK(4),MAXNQ(4),MFE
     1(4),MLC(4),MLE(4),NCELLS(15),NQ(4),PARAMS(20,4),QTIME(4),SSUMA(10,
     25),SUMA(10,5),IX(8)
      COMMON NCEL,FRAC1,FRAC2,NT,SX,SY,F1,XD,YD,XH,XC1,XC2,LCON,LDIST,TT
     11,TT2,PT1,A1,A2,C1,C2,HRS,DELTA
      COMMON TBD,TLD,NSYS,NTRN,TEMPTY,WAITIN,THEAT,NCOLD,TCRUT,NINGR,NRE
     1P,KR,TCEL,CT,PU,TEL,TX,TY,LD,NC,TQ,ND,RED
      DIMENSION NSET(6,1)
      ST=ATTRIB(3)
      I4=ATTRIB(4)
      NTRN=ATTRIB(4)
C
C**** COLLECT STATISTICS ON NQ(2) AND NTRN
C
      CALL HISTOG(FLOAT(NTRN),0.0,1.0,9)
      CALL TMSTAT(FLOAT(NQ(2)),TNOW,2,NSET)
   90 IF(NQ(2))19,61,100
C
C**** CHECK WHETHER A TRAIN IS WAITING FOR MORE THAN TQ HRS
C
  100 IF(TNOW-NSET(ATTRIB(3),MLE(2))/SCALE-TQ)61,61,60
   19 CALL ERROR(40,NSET)
   60 MLE2=MLE(2)
      CALL REMOVE(MLE2,2,NSET)
      NCOLD=NCOLD+1
      GO TO 90
   61 I2=I4
   25 ATTRIB(1)=LCON+I2*LDIST
      ATTRIB(2)=0
      ATTRIB(3)=ST
      ATTRIB(4)=0
      CALL FILEM(2,NSET)
      I2=I2-1
C
C**** CHECK WHETHER THE ARIVL WAS FILED IN FILE 2
C
      IF(I2.GT.0) GO TO 25
C
C**** INTER ARRIVAL TIME IS ASSUMED TO BE ERLANG 4
C
      ER=ERLANG(4,2)
      CALL COLECT(ER,8,NSET)
      CALL HISTOG(ER,.0,0.1,5)
C
C**** SCHEDULE NEXT ARRIVAL
C
```

```
      TIME=TNOW+ER
C
C**** GENERATE THE NUMBER OF INGOTS OTHE TRAIN
C
      NN=RNORML(5,1)
C
C**** FILE THE ARIVL INTO THE EVENT FILE
C
      ATTRIB(1)=TIME
      ATTRIB(2)=1.0
      ATTRIB(3)=TIME
      ATTRIB(4)=NN
      CALL FILEM(1,NSET)
C
C**** CHECK WHETHER THE CRANE IS IDLE
C
      IF(KR)30,40,50
   30 CALL ERROR(41,NSET)
   50 RETURN
   40 KR=2
      CALL ECRANE(NSET)
      RETURN
      END
```

```
      SUBRCUTINE ECRANE(NSET)
      COMMCN ID,IM,INIT,JEVENT,JMONIT,MFA,MSTOP,MX,MXC,NCOLCT,NHISTO,NOQ
     1,NORPT,NOT,NPRAMS,NRUN,NRUNS,NSTAT,OUT,SCALE,NSEED,TNOW,TSTART,TST
     2OP,MXX
      COMMCN ATTRIB(4),ENQ(4),INN(4),JCELLS(15,22),KRANK(4),MAXNQ(4),MFE
     1(4),MLC(4),MLE(4),NCELLS(15),NQ(4),PARAMS(20,4),QTIME(4),SSUMA(10,
     25),SUMA(10,5),IX(8)
      COMMCN NCEL,FRAC1,FRAC2,NT,SX,SY,F1,XD,YD,XH,XC1,XC2,LCON,LDIST,TT
     11,TT2,PT1,A1,A2,C1,C2,HRS,DELTA
      COMMCN TBD,TLD,NSYS,NTRN,TEMPTY,WAITIN,THEAT,NCOLD,TCRUT,NINGR,NRE
     1P,KR,TCEL,CT,PU,TEL,TX,TY,LD,NC,TQ,ND,RED
      DIMENSION NSET(6,1)
      CALL HISTOG(FLOAT(NQ(4)),0.0,3.0,10)
C
C**** DETERMINE THE TYPE OF CRANE SERVICE
C
      GO TC (10,20,30),KR
C
C**** CHARGING ARRIVING INGOTS
C
   20 IF(NQ(2))21,40,50
   50 IF(NQ(4))22,40,70
   21 CALL ERROR(21,NSET)
   22 CALL ERROR(22,NSET)
   70 TCRUT=TCRUT+CT
      CT=CT*60.0
C
C**** COLLECT STATISTICS ON CRANE TIMES
C
      CALL COLECT(CT,2,NSET)
      CALL HISTOG(CT,0.6,0.10,4)
      CALL TMSTAT(FLOAT(NQ(2)),TNOW,2,NSET)
      MFE2=MFE(2)
      CALL REMOVE(MFE2,2,NSET)
C
C**** COLLECT STATISTICS ON WAITING TIME FOR ARRIVING INGOTS
C
      WAITIN=TNOW-ATTRIB(3)
      WAITIN=WAITIN*60.0
      CALL COLECT(WAITIN,1,NSET)
      CALL HISTOG(WAITIN,0.0,2.0,8)
C
C**** CRANE TIME IS THE MAX. TRAVEL TIME PLUS A CONSTANT
C
      CT=F1+AMAX1((ATTRIB(1)+DRAND(1)*XD)/SX,DRAND(2)*YD/SY)
      L1=1
      ATTRIB(1)=TNOW+CT
      ATTRIB(2)=2.0
      ATTRIB(4)=L1
C
C**** SCHECULE HEATING TIME EVENT
```

```
C
      CALL FILEM(1,NSET)
      ATTRIB(2)=3.0
C
C**** SCHEDULE END OF CRANE SERVICE TIME
C
      CALL FILEM(1,NSET)
C**** CHECK PRIORITY FOR CRANE
C
  150 XY=FLOAT(NQ(4))/FLOAT(NCEL)
      IF(XY-FRAC2)80,90,90
   80 KR=3
      RETURN
   90 IF(XY-FRAC1)100,110,110
  100 KR=2
      RETURN
  110 KR=1
      RETURN
C
C**** CRANE DRAWING SOAKED INGOTS
C
   30 IF(NQ(3))31,120,140
  120 KR=2
      GO TO 20
   31 CALL ERROR(31,NSET)
  140 TCRUT=TCRUT+CT
      CT=CT*60.0
      CALL COLECT(CT,2,NSET)
      CALL HISTOG(CT,0.6,0.10,4)
      MFE3=MFE(3)
      CALL REMOVE(MFE3,3,NSET)
C
C**** COLLECT STATISTICS ON TCEL, THWAIT, AND THEAT
C
      TCEL=TNOW-ATTRIB(3)
      CALL COLECT(TCEL,3,NSET)
      THWAIT=TNOW-ATTRIB(1)
      THWAIT=THWAIT*60.0
      CALL COLECT(THWAIT,4,NSET)
      CALL HISTOG(THWAIT,0.0,1.0,3)
C
C**** SCHEDULE SERVICE TIME FOR SOAKED INGOTS
C
      CT=F1+AMAX1((XH+(1-DRAND(1))*XD)/SX,DRAND(2)*YD/SY)
      ATTRIB(1)=TNOW+CT
      ATTRIB(2)=3.0
      CALL FILEM(1,NSET)
      NSYS=NSYS+1
  240 TBD=TNOW-TLD
      TLD=TNOW
      TBD=TBD*60.0
```

```
      CALL COLECT(TBD,5,NSET)
      IF(TBD-10.0)210,210,220
  210 CALL HISTOG(TBD,0.0,0.5,6)
      GO TO 230
  220 CALL HISTOG(TBD,10.0,2.0,7)
  230 ATTRIB(1)=TNOW
      CALL TMSTAT(FLOAT(NQ(4)),TNOW,1,NSET)
      CALL FILEM(4,NSET)
      GO TO 150
   40 IF(NQ(3))169,170,171
  169 CALL ERROR(32,NSET)
  170 KR=0
      RETURN
  171 KR=3
      GO TO 140
C
C**** CHARGING COLD INGOTS
C
   10 IF(NCOLD-NC)150,160,161
  159 CALL ERROR(12,NSET)
  160 KR=2
      GO TO 20
  161 IF(NQ(4))39,40,200
   39 CALL ERROR(12,NSET)
  200 NC=NC+1
      TCRUT=TCRUT+CT
      CT=CT*60.0
      CALL COLECT(CT,2,NSET)
      CALL HISTOG(CT,0.6,0.10,4)
C
C**** CRANE SERVICE TIME FOR COLD INGOTS
C
      CT=F1+AMAX1((UNIFRM(XC1,XC2,3)+DRAND(1)*XD)/SX,(1-DRAND(2))*YD/SY)
      ATTRIB(1)=TNOW+CT
      L1=2
      ATTRIB(2)=2.0
      ATTRIB(4)=L1
C
C**** SCHEDULE HEATING TIME EVENT
C
      CALL FILEM(1,NSET)
C
C**** SCHEDULE END OF CRANE SERVICE TIME
C
      ATTRIB(2)=3.0
      CALL FILEM(1,NSET)
      GO TO 150
      END
```

```
      SUBROUTINE EHEAT(NSET)
      COMMON ID,IM,INIT,JEVENT,JMONIT,MFA,MSTOP,MX,MXC,NCOLCT,NHISTO,NOQ
     1,NORPT,NOT,NPRAMS,NRUN,NRUNS,NSTAT,OUT,SCALE,NSEED,TNOW,TSTART,TST
     2OP,MXX
      COMMON ATTRIB(4),ENQ(4),INN(4),JCELLS(15,22),KRANK(4),MAXNQ(4),MFE
     1(4),MLC(4),MLE(4),NCELLS(15),NQ(4),PARAMS(20,4),QTIME(4),SSUMA(10,
     25),SUMA(10,5),IX(8)
      COMMON NCEL,FRAC1,FRAC2,NT,SX,SY,F1,XD,YD,XH,XC1,XC2,LCON,LDIST,TT
     11,TT2,PT1,A1,A2,C1,C2,HRS,DELTA
      COMMON TBD,TLD,NSYS,NTRN,TEMPTY,WAITIN,THEAT,NCOLD,TCRUT,NINGR,NRE
     1P,KR,TCEL,CT,PU,TEL,TX,TY,LD,NC,TQ,ND,RED
      DIMENSION NSET(6,1)
      XT=ATTRIB(3)
      L1=ATTRIB(4)
      CALL TMSTAT(FLOAT(NQ(4)),TNOW,1,NSET)
      MFE4=MFE(4)
      CALL REMOVE(MFE4,4,NSET)
      ATTRIB(3)=XT
C
C**** CHECK WHETHER IT IS A COLD OR A HOT INGOT
C
      IF(L1-1)71,30,31
   31 IF(L1-2)71,40,71
   71 PRINT 6,L1
    6 FORMAT('     HEATING TIME CONSTANT WRONG =',I5)
      CALL ERROR(71,NSET)
C
C**** X IS A FUNCTION OF TRACK TIME
C
   30 X=TNOW-ATTRIB(3)
      X=X+RNORML(7,3)
      IF(X-TT2)10,10,20
   10 THEAT=A1*(X-TT1)**2+PT1
      GO TO 50
   20 THEAT=A1*(TT2-TT1)**2+PT1+A2*(X-TT2)
      IF(THEAT-C1)50,50,80
   80 THEAT=C1
      GO TO 50
   40 THEAT=UNIFRM(C1,C2,6)
C
C**** SCHEDULE COMPL EVENT
C
   50 ATTRIB(1)=TNOW+THEAT
      ATTRIB(2)=6.0
      ATTRIB(3)=TNOW
      ATTRIB(4)=THEAT
      CALL FILEM(1,NSET)
      RETURN
      END
```

```
      SUBRCUTINE COMPL(NSET)
      COMMCN ID,IM,INIT,JEVENT,JMONIT,MFA,MSTOP,MX,MXC,NCOLCT,NHISTO,NOQ
     1,NORPT,NOT,NPRAMS,NRUN,NRUNS,NSTAT,OUT,SCALE,NSEED,TNOW,TSTART,TST
     2OP,MXX
      COMMCN ATTRIB(4),ENQ(4),INN(4),JCELLS(15,22),KRANK(4),MAXNQ(4),MFE
     1(4),MLC(4),MLE(4),NCELLS(15),NQ(4),PARAMS(20,4),QTIME(4),SSUMA(10,
     25),SUMA(10,5),IX(8)
      COMMCN NCEL,FRAC1,FRAC2,NT,SX,SY,F1,XD,YD,XH,XC1,XC2,LCON,LDIST,TT
     11,TT2,PT1,A1,A2,C1,C2,HRS,DELTA
      COMMCN TBD,TLD,NSYS,NTRN,TEMPTY,WAITIN,THEAT,NCOLD,TCRUT,NINGR,NRE
     1P,KR,TCEL,CT,PU,TEL,TX,TY,LD,NC,TQ,ND,RED
      DIMENSION NSET(6,1)
      THEAT=ATTRIB(4)
      CALL COLECT(THEAT,6,NSET)
      CALL HISTOG(THEAT,2.0,0.5,1)
      CALL FILEM(3,NSET)
C
C**** CHECK WHETHER THE CRANE IS IDLE
C
      IF(KR)10,10,20
   20 RETURN
   10 XY=FLOAT(NQ(4))/FLOAT(NCEL)
      IF(XY-FRAC2)80,90,90
   80 KR=3
      CALL ECRANE(NSET)
      RETURN
   90 IF(XY-FRAC1)100,110,110
  100 KR=2
      CALL ECRANE(NSET)
      RETURN
  110 KR=1
      CALL ECRANE(NSET)
      RETURN
      END
```

```
      SUBROUTINE HREP(NSET)
      COMMON ID,IM,INIT,JEVENT,JMONIT,MFA,MSTOP,MX,MXC,NCOLCT,NHISTO,NOQ
     1,NORPT,NOT,NPRAMS,NRUN,NRUNS,NSTAT,OUT,SCALE,NSEED,TNOW,TSTART,TST
     2OP,MXX
      COMMON ATTRIB(4),ENQ(4),INN(4),JCELLS(15,22),KRANK(4),MAXNQ(4),MFE
     1(4),MLC(4),MLE(4),NCELLS(15),NQ(4),PARAMS(20,4),QTIME(4),SSUMA(10,
     25),SUMA(10,5),IX(8)
      COMMON NCEL,FRAC1,FRAC2,NT,SX,SY,F1,XD,YD,XH,XC1,XC2,LCON,LDIST,TT
     11,TT2,PT1,A1,A2,C1,C2,HRS,DELTA
      COMMON TBD,TLD,NSYS,NTRN,TEMPTY,WAITIN,THEAT,NCOLD,TCRUT,NINGR,NRE
     1P,KR,TCEL,CT,PU,TEL,TX,TY,LD,NC,TQ,ND,RED
      DIMENSION NSET(6,1)
C
C**** GENERATE NEXT HREP
C
      ATTRIB(1)=TNOW+HRS
      ATTRIB(2)=4.0
      CALL FILEM(1,NSET)
      NS=NCOLD-NC
      NINGR=NSYS-NINGR
      CALL COLECT(FLOAT(NINGR),7,NSET)
      CALL HISTOG(FLOAT(NINGR),0.0,2.0,2)
      PU=TCRUT-PU
      TX=TX+PU
C
C**** X=GRAND AVRG. UTILIZATION OF THE CRANE. XF= UTILIZATION INITIALIZED
C      AT 30 HOURS
C
      X=TCRUT*100.0/TNOW
      XF=TX*100.0/RED
      ND=ND+NINGR
C
C**** XI = GRAND AVRG. OUTPUT . XG= GRAND. AVRG. OUTPUT INITIALIZED AT
C      AT 30 HOURS
C
      XI=NSYS*100.0/TNOW
      XG=FLOAT(ND)/RED*100.0
C
C**** CRANE UTILIZATION, PERCENT = XX
C
      XX=PU*100.0/HRS
      IF(XX-100.0)20,20,30
   30 XX=100.0
   20 PRINT 16,TNOW,NINGR,XI,XG,NCOLD,NC,NS,(NQ(I),I=2,4),XX,X,XF
   16 FORMAT(1H0,F8.2,I9,2F9.2,6I9,3F9.2)
      PU=TCRUT
      NINGR=NSYS
      RED=RED+HRS
      RETURN
      END
```

```
      SUBROUTINE REPORT(NSET)
      COMMON ID,IM,INIT,JEVENT,JMONIT,MFA,MSTOP,MX,MXC,NCOLCT,NHISTO,NOQ
     1,NORPT,NOT,NPRAMS,NRUN,NRUNS,NSTAT,OUT,SCALE,NSEED,TNOW,TSTART,TST
     2OP,MXX
      COMMON ATTRIB(4),ENQ(4),INN(4),JCELLS(15,22),KRANK(4),MAXNQ(4),MFE
     1(4),MLC(4),MLE(4),NCELLS(15),NQ(4),PARAMS(20,4),QTIME(4),SSUMA(10,
     25),SUMA(10,5),IX(8)
      COMMON NCEL,FRAC1,FRAC2,NT,SX,SY,F1,XD,YD,XH,XC1,XC2,LCON,LDIST,TT
     11,TT2,PT1,A1,A2,C1,C2,HRS,DELTA
      COMMON TBD,TLD,NSYS,NTRN,TEMPTY,WAITIN,THEAT,NCOLD,TCRUT,NINGR,NRE
     1P,KR,TCEL,CT,PU,TEL,TX,TY,LD,NC,TQ,ND,RED
      DIMENSION NSET(6,1)
C
C**** GENERATE NEXT REPORT
C
      ATTRIB(1)=TNOW+DELTA
      ATTRIB(2)=5.0
      CALL FILEM(1,NSET)
      NREP=NSYS-NREP-IFIX(TY)
      TY=0.0
      CALL COLECT(FLOAT(NREP),9,NSET)
      CALL SUMARY(NSET)
      CALL OUTPUT(NSET)
      NREP=NSYS
      RETURN
      END
```

```
      SUBROUTINE OUTPUT(NSET)
      COMMON ID,IM,INIT,JEVENT,JMONIT,MFA,MSTOP,MX,MXC,NCOLCT,NHISTO,NOQ
     1,NORPT,NOT,NPRAMS,NRUN,NRUNS,NSTAT,OUT,SCALE,NSEED,TNOW,TSTART,TST
     2OP,MXX
      COMMON ATTRIB(4),ENQ(4),INN(4),JCELLS(15,22),KRANK(4),MAXNQ(4),MFE
     1(4),MLC(4),MLE(4),NCELLS(15),NQ(4),PARAMS(20,4),QTIME(4),SSUMA(10,
     25),SUMA(10,5),IX(8)
      COMMON NCEL,FRAC1,FRAC2,NT,SX,SY,F1,XD,YD,XH,XC1,XC2,LCON,LDIST,TT
     11,TT2,PT1,A1,A2,C1,C2,HRS,DELTA
      COMMON TBD,TLD,NSYS,NTRN,TEMPTY,WAITIN,THEAT,NCOLD,TCRUT,NINGR,NRE
     1P,KR,TCEL,CT,PU,TEL,TX,TY,LD,NC,TQ,ND,RED
      DIMENSION NSET(6,1)
      IT=0
      DO 10 I=1,22
   10 IT=IT+JCELLS(10,I)
      X1=FLOAT(JCELLS(10,1))/FLOAT(IT)
   20 FORMAT(1H1,'PROBABILITY THAT THE PIT IS FULL =',F7.4)
      PRINT 20,X1
      RETURN
      END
```

```
      SUBROUTINE INST(NSET)
      COMMON ID,IM,INIT,JEVENT,JMONIT,MFA,MSTOP,MX,MXC,NCOLCT,NHISTO,NOQ
     1,NORPT,NOT,NPRAMS,NRUN,NRUNS,NSTAT,OUT,SCALE,NSEED,TNOW,TSTART,TST
     2OP,MXX
      COMMON ATTRIB(4),ENQ(4),INN(4),JCELLS(15,22),KRANK(4),MAXNQ(4),MFE
     1(4),MLC(4),MLE(4),NCELLS(15),NQ(4),PARAMS(20,4),QTIME(4),SSUMA(10,
     25),SUMA(10,5),IX(8)
      COMMON NCEL,FRAC1,FRAC2,NT,SX,SY,F1,XD,YD,XH,XC1,XC2,LCON,LDIST,TT
     11,TT2,PT1,A1,A2,C1,C2,HRS,DELTA
      COMMON TBD,TLD,NSYS,NTRN,TEMPTY,WAITIN,THEAT,NCOLD,TCRUT,NINGR,NRE
     1P,KR,TCEL,CT,PU,TEL,TX,TY,LD,NC,TQ,ND,RED
      DIMENSION NSET(6,1)
      DO 18 I=1,NCOLCT
      DO 17 J=1,3
   17 SUMA(I,J)=0.
      SUMA(I,4)=1.0E20
   18 SUMA(I,5)=-1.0E20
      DO 360 I=1,NSTAT
      DO 370 J=1,3
  370 SSUMA(I,J)=0.
      SSUMA(I,4)=1.0E20
  360 SSUMA(I,5)=-1.0E20
      DO 380 K=1,NHISTO
      DO 380 L=1,MXC
  380 JCELLS(K,L)=0
      TX=0.0
      ND=0
      TY=NSYS
      RED=HRS
      NC=0
      NCOLD=0
C
C**** SCHEDULE REPORT
C
      ATTRIB(1)=TNOW+DELTA
      ATTRIB(2)=5.0
      CALL FILEM(1,NSET)
      RETURN
      END
```

GASP SUMMARY REPORT

GENERATED DATA

CODE	MEAN	STD.EV.	MIN	MAX.	OBS.
1	7.16	6.64	0.01	67.43	2795
2	1.57	0.16	1.20	2.09	5755
3	3.11	1.19	2.50	10.32	2871
4	4.59	5.96	0.01	35.89	2871
5	4.18	4.80	1.25	39.83	2871
6	3.04	1.18	2.50	9.99	2869
7	14.35	4.17	4.00	22.00	201
8	0.50	0.26	0.10	1.50	404
9	1435.50	38.89	1408.00	1463.00	2

TIME GENERATED DATA

CODE	MEAN	ST D.DEV.	MIN.	MAX.	TOTAL TIME
1	15.41	6.62	0.0	35.00	229.995
2	1.59	2.44	0.0	14.00	230.020

GENERATED FREQUENCY DISTRIBUTIONS

CODE	HISTOGRAMS																					
1	0	0	2154	393	135	50	28	7	8	3	0	0	0	24	23	19	25	0	0	0	0	0
2	0	0	0	5	9	17	22	26	37	33	31	17	4	0	0	0	0	0	0	0	0	0
3	0	1092	417	175	131	93	106	95	115	80	85	75	69	64	41	35	34	39	20	10	10	85
4	0	0	0	0	0	0	0	215	635	1043	1487	1174	752	304	119	26	0	0	0	0	0	0
5	0	0	34	60	81	56	60	32	26	25	14	3	5	6	0	1	1	0	0	0	0	0
6	0	0	0	635	966	67	85	139	67	64	206	90	37	35	41	20	32	13	20	20	20	0
7	0	69	72	64	35	24	17	8	5	8	2	5	1	0	2	2	0	0	0	0	0	0
8	0	570	409	408	418	329	218	145	92	66	39	34	16	11	6	6	3	2	4	1	0	18
9	0	0	0	0	0	2	15	81	156	109	37	4	0	0	0	0	0	0	0	0	0	0
10	52	151	362	465	1527	1172	799	615	548	425	364	74	10	0	0	0	0	0	0	0	0	0

QUEUE PRINTOUT, QUEUE NO. 1

AVERAGE NO. OF ITEMS IN THE QUEUE WAS 46.627

MAXIMUM 64

QUEUE CONTENTS

230.0449	2.0000	229.9942	1.0000
230.0449	3.0000	229.9942	1.0000
230.0642	6.0000	227.5642	2.5000
230.0763	6.0000	227.2712	2.8050
230.0962	6.0000	227.3551	2.7410

230.1244	6.0000	227.6165	2.5078
230.1650	6.0000	227.3836	2.7813
230.2096	6.0000	227.6981	2.5115
230.2887	6.0000	227.6421	2.6466
230.4087	6.0000	227.7786	2.6300
230.4244	6.0000	226.4453	3.9790
230.5297	6.0000	227.5921	2.9375
230.6840	1.0000	230.6840	8.0000
230.8427	6.0000	228.1498	2.6929
230.8580	6.0000	222.2345	8.6234
230.8630	6.0000	228.2932	2.5697
230.9145	6.0000	228.1266	2.7879
230.9405	6.0000	228.2038	2.7366
231.0000	4.0000	0.0	0.0
231.0354	6.0000	228.1783	2.8570
231.0890	6.0000	228.2604	2.8285
231.1466	6.0000	227.6671	3.4794
231.2586	6.0000	228.7582	2.5003
231.3055	6.0000	228.6452	2.6603
231.5415	6.0000	228.9953	2.5461
231.6461	6.0000	228.8177	2.8283
231.7416	6.0000	228.6972	3.0444
231.7916	6.0000	229.2896	2.5020
231.8136	6.0000	223.5318	8.2817
231.8453	6.0000	222.6621	9.1832
231.8579	6.0000	223.5636	8.2942
231.8841	6.0000	229.0924	2.7916
231.8868	6.0000	229.3369	2.5498
231.9107	6.0000	229.2280	2.6827
231.9527	6.0000	229.3905	2.5621
231.9625	6.0000	229.1203	2.8421
231.9685	6.0000	228.6709	3.2975
232.0121	6.0000	229.4776	2.5344
232.0241	6.0000	228.7278	3.2962
232.0484	6.0000	222.2087	9.8397
232.0944	6.0000	229.2588	2.8355
232.1110	6.0000	228.2336	3.8773
232.1793	6.0000	222.6908	9.4884
232.2041	6.0000	229.6998	2.5042
232.2313	6.0000	229.3613	2.8700

232.3237	6.0000	229.1754	3.1482
232.3327	6.0000	229.6394	2.6932
232.4048	6.0000	223.6741	8.7306
232.5919	6.0000	228.7846	3.8072
232.6032	6.0000	229.2046	3.3985
232.8456	6.0000	229.4478	3.3977
232.8727	6.0000	223.6429	9.2297
233.1795	6.0000	229.7265	3.4529
233.2638	6.0000	229.4172	3.8465
233.4691	6.0000	229.7860	3.6830
233.4863	6.0000	228.9742	4.5120
234.3259	6.0000	229.9157	4.4101
234.8031	6.0000	229.8902	4.9128
234.9759	6.0000	229.7562	5.2196
235.2776	6.0000	229.6689	5.6086
330.0000	5.0000	0.0	0.0

QUEUE PRINTOUT, QUEUE NO. 2

AVERAGE NO. OF ITEMS IN THE QUEUE WAS 1.885

MAXIMUM 14

QUEUE CONTENTS

25.0000	0.0	229.9943	0.0
30.0000	0.0	229.9943	0.0
35.0000	0.0	229.9943	0.0
40.0000	0.0	229.9943	0.0
45.0000	0.0	229.9943	0.0
50.0000	0.0	229.9943	0.0
55.0000	0.0	229.9943	0.0

QUEUE PRINTOUT, QUEUE NO. 3

AVERAGE NO. OF ITEMS IN THE QUEUE WAS 1.048

MAXIMUM 11

QUEUE CONTENTS

THE QUEUE IS EMPTY

QUEUE PRINTOUT, QUEUE NO. 4

AVERAGE NO. OF ITEMS IN THE QUEUE WAS 15.410

MAXIMUM 60

QUEUE CONTENTS

229.8376	3.0000	227.3305	2.5008

229.9480	3.0000	227.2450	2.7028
229.9689	3.0000	227.3004	2.6490
229.9948	3.0000	227.4162	2.5618

PROBABILITY THAT THE PIT IS FULL = 0.0079

NCEL = 60

FRAC2 = 0.20

FRAC1 = 0.50

SX = 6000.

SY = 3000.

F1 = 0.016670

XD = 50.

YD = 30.

XH = 25.

XC1 = 30.

XC2 = 50.

LCON = 15

LDIST = 5

TT1 = 0.50

TT2 = 1.50

PT1 = 2.50

A1 = 3.00

A2 = 1.20

C1 = 8.00

C2 = 10.00

HRS = 1.00

DELTA = 100.

MAX. TIME THE TRAIN CAN WAIT = 2.00

SIMULATION PROJECT NO. 1 BY REDDY

DATE 4/ 14/ 1969

PARAMETER NO.	1	7.7500	4.0000	11.0000	1.0000
PARAMETER NO.	2	0.1250	0.1000	1.5000	4.0000
PARAMETER NO.	3	0.5000	0.0	1.5000	0.3000

SCALE= 10000.

SIMULATION OF A BULK ARRIVAL QUEUEING SYSTEM WITH REFERENCE TO A SOAKING PIT

by

N. N. JANARDHANA REDDY

B.E. (Mechanical), Sri Venkateswara University, India, 1966

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Industrial Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1969

Simulation is used to study soaking pit operation. This model does not include the teeming and stripping operations, it assumes ingots arriving in batches at random intervals of time. The rolling mill restriction is removed and the ingots are drawn from the soaking pit after being heated to the required conditions if the crane is available.

The type of crane operation--charging arriving ingots, charging cold ingots and drawing soaked ingots--based on the fraction of the cells empty, is important. The two fractions which decide the type of crane operation, are dependent mainly on the average utilization of the pit. Better results can be achieved by reducing the fractions, when the utilization of the pit is increasing. But when the fraction, which decides either the charging of arriving ingots or cold ingots, is reduced from 0.5 to 0.4, the system created 50 percent more cold ingots, which will effect the economy of the soaking pit operation. The determination of the exact fractions are left to the future research due to the large amount of computer time required.