1960

A Monte Carlo simulation of a materuak handling system

Marlyn L. Rabenold
Lehigh University

Recommended Citation

Rabenold, Marlyn L., "A Monte Carlo simulation of a materuak handling system" (1960). *Theses and Dissertations*. 3016.
https://preserve.lehigh.edu/etd/3016

A MONTE CARLO SIMULATION OF
A MATERIAL HANDLING SYSTEM

by

Marlyn L. Rabenold

A THESIS

Presented to the Graduate Faculty

of Lehigh University

in Candidacy for the Degree of

Master of Science

in Industrial Engineering

Lehigh University

1960

CERTIFICATE OF APPROVAL

This thesis is accepted and approved in partial fulfillment of the requirements for the degree of Master of Science.

May 26, 1960
(Date)

Arthur F. Jones
Professor in Charge

Arthur F. Jones
Head of the Department

ACKNOWLEDGMENTS

I should like to express my appreciation to all those people who contributed their time and effort in making this study possible. I particularly wish to thank:

The United States Steel Corporation for its endorsement of the study;

Mr. Frank Lubick, who gave me his wholehearted support in collection of the information;

Professor Sutton Monro, who gave me assistance and invaluable aid in the analysis and preparation of the data;

Miss Ruth Koppe and Mr. David Wood, who assisted me in programming the problem for the LGP-30;

Professor Arthur F. Gould, who gave me guidance and advice on the general approach to the problem.

TABLE OF CONTENTS

APPENDICES

TABLE OF CONTENTS (Cont'd)

APPENDICES (Cont'd)

LIST of TABLES

LIST of TABLES (Cont'd)

Table Page

LIST OF FIGURES

Figure Page

INTRODUCTION

As an expression of appreciation for the receipt of a United States Steel Corporation Fellowship, the Corporation was asked if they had any problems which they would like to have solved and which at the same time would also be suitable for a thesis in Industrial Engineering. Thus, it was hoped that a thesis could be written and at the same time a particular operating problem of the United States Steel Corporation solved.

The main office of the Corporation referred us to one of their operating plants where the Chief Industrial Engineer was approached with the thought of helping him solve one of his problems and at the same time fulfill the requirements for a thesis in Industrial Engineering. Three problems which they wanted to have solved were presented to us. Of these, one was selected as being most applicable to a thesis in Industrial Engineering.

The problem selected was stated as follows: "How many ingot buggies should we have?"

It was decided that the first two steps of the study should be:

1. To completely understand the physical operation.[1]
2. To collect what information was available.

---

[1] Of course, the paramount question at this time was, "What's an ingot buggy?"

DESCRIPTION OF THE SYSTEM

The system studied was that part of the overall system for making steel which involves the utilization of ingot buggies. Ingot buggies are actually small, standard gage railroad cars which are used to transport steel from the open hearth, where it is made, to the rolling mill, where it is converted into a finished product.[1] Basically, then, the system studied is a material handling system.

Following is a description of this material handling system. First is given a general description of the areas involved in the system, and then a description of the ingot buggies themselves.

A. Open Hearths

At this plant, steel is produced in nine open hearth furnaces. At the time of the study, seven of the nine furnaces had a capacity of 375 tons,[2] one furnace (#2 furnace) had a capacity of 400 tons, and the remaining furnace was in the process of being converted from a capacity of 375 tons to a capacity of 400 tons. The plans of this plant were to increase total plant capacity to 3,000,000 ingot tons per year by converting all of the furnaces to a capacity of 400 tons.

---

[1] A glossary of terms has been provided in Appendix A.

[2] A capacity of 375 tons means that the furnace can produce 375 tons of steel at any one time.

B. Pouring Area

The pouring area, commonly called the open hearth pit, is the area in which molten steel is poured into molds to form ingots. This area, which is in the same building as the open hearths (See Figure 1, Appendix B), is several hundred yards long. It is open at both ends and is bounded on one side by the open hearth furnaces and on the other side by the pouring platforms. The floor of the area, which is actually the ground, has railroad tracks running along the side with the pouring platforms.

When steel is ready to be poured a string of ingot buggies, collectively referred to as a drag, is moved into the area to one of its three pouring platforms. Setting on these ingot buggies are molds into which molten steel will be poured to form ingots.

The steel which is to be poured is tapped from the furnace into a ladle. The ladle is moved by overhead cranes across the floor to the pouring platforms where the drag of ingot buggies is waiting. The molten steel is then poured from the ladle, still supported by the overhead crane, into the molds. After pouring, the drag is not moved until a specified minimum metallurgical holding time has elapsed.[3] After this minimum time has elapsed, the drag of ingot buggies is moved to the stripping mill.

---

3. If moved before this time there is danger of the molten ingots exploding.

C. Stripping Mill

The function of the stripping mill, commonly called the stripper, is to remove the molds from the ingots, which by this time have solidified (See Figure 3, Appendix B). The stripper is actually a shell of a building, open at both ends with two overhead cranes. The drag of cars with molds to be stripped is moved into the stripper. The overhead cranes then remove the molds from the ingots and place them on to an empty drag of cars which was previously moved into the stripper. The drag of empty molds is moved to the mold yard where the molds are reconditioned and the drag of ingots is moved to the soaking pits.

D. Soaking Pits

The soaking pits are really open-topped gas fired furnaces used to bring the ingots to a uniform temperature.[4] After the drag of ingots is brought into the soaking pit area, the ingots are removed from the ingot buggies and placed into the pits, called charging the ingots, by an overhead crane. When the drag of cars is empty, it is returned to the stripper where it awaits the arrival of a drag of ingots. The molds which are stripped are placed on this drag and it is then moved to the mold yard.

---

[4] When the ingots arrive at the soaking pits, the inside of the ingot is still molten even though the surface has solidified. Before being rolled the ingot must be solidified and brought to a uniform temperature throughout.

E. Mold Yard

The mold yard, which is in the same building as the open hearths, runs parallel to the pouring area, being separated by the pouring platforms. It is here that the molds are reconditioned for reuse. Reconditioning of the molds is done by dipping them into a tank of liquid, coating them with a substance which facilitates removal of the ingot from the mold and which also improves the quality of the steel. After coating, the molds are placed on the drag of ingot buggies which will be moved into the pouring area.

F. Summary of Normal Ingot Buggy Cycle

To help clarify the material handling system studied, a summary of the normal, trouble-free ingot buggy cycle follows.

1. Steel poured in molds at the pouring platform.
2. Held for minimum holding time.
3. Moved to stripper.
4. Ingots stripped.
5. Moved to soaking pits.
6. Ingots charged.
7. Returned to stripper.
8. Empty ingots loaded on drag.
9. Moved to mold yard.
10. Molds reconditioned
11. Moved to pouring platform.

G. Ingot Buggies

As was stated before, an ingot buggy is actually a small, flat, heavy-duty railroad car. It is used to transport molds and ingots through the system just described.

There is only one basic type of ingot buggy used. However, on the basic car itself is placed a cast iron slab, called a stool, on which the molds set (See Figure 3, Appendix B). There are two types of stools called B stools and C stools used on the cars. These stools, once placed on cars, are not removed until they have to be replaced. Thus, in essence, there are two types of ingot buggies, referred to as B cars and C cars. The reason for the different types of stools, and thus types of ingot buggies, is to accommodate the different sizes of molds. Each size mold has specified the type of car that must be used to transport it.

H. Inoperative Ingot Buggies

The term inoperative ingot buggies means those ingot buggies which are out of operation and cannot be used to transport ingots from the open hearth to stripper. There are four primary reasons why an ingot buggy would be inoperative.

1. The ingot buggy is being used to transport stickers. A sticker is an ingot from which the mold cannot be pulled by the stripping crane. These ingots are sent back to the open hearth area where the mold is burned off by use of an acetylene torch.

H. Inoperative Ingot Buggies (Continued)

2. The ingot buggy is being used as a shop buggy. A shop buggy is the name given to an ingot buggy which is being used in the open hearth area for spare parts. For example, if a set of wheels on a buggy which is in a drag is frozen, they will usually not remove the whole buggy but rather just replace the wheels with a set from a shop buggy.

3. The ingot buggy is being used to store cold steel. Sometimes, for various reasons, such as no soaking pit room, the ingots will not be charged but rather will be allowed to cool. These cold ingots, called cold steel, are usually moved to the South Yard where they are stored until they are to be rolled. Ingot buggies are, of course, needed to transport them to the South Yard, and in addition, the ingots themselves are sometimes stored directly on the ingot buggies, thus removing buggies from the normal cycle.

4. The ingot buggy is out for repairs and maintenance. Ingot buggies, simple and as well constructed as they are, also break down and need to be repaired.

Besides the four reasons mentioned above, there are other reasons why ingot buggies are not being used to transport ingots and molds. The two primary reasons are (1) an ingot buggy is being used as a snowplow,[5] and (2) an ingot

---

[5] Only applies in wintertime, of course.

buggy is being used as a spacer car. A spacer car is an extra car placed between the locomotive and drag to separate the locomotive from the heat of the ingots. However, ingot buggies do not have to be used for these purposes since there are other cars available which would serve the purpose just as well.

THE PROBLEM

The problem as stated by U. S. Steel was simply, "How many ingot buggies should we have?". Since this statement is too broad to use as an objective for the solution of the problem, the problem first had to be defined.

A. Definition of the Problem

The problem as stated above did not include any criterion for making the decision of how many ingot buggies should be available. Since the primary purpose of the Corporation is to make a profit, the decision criterion should be maximum profits to the Corporation. However, profits are not directly associated with ingot buggies, but since profits can be maximized by minimizing costs,[1] the decision criterion should be the lowest total cost to the Corporation.

In addition, two other questions have to resolved. One is the question of correct methods and the other is the question of plant output.

Since we were concerned with "How many ingot buggies should we have?" and not "How can we best utilize the ingot buggies that we do have?", no methods or improvements were contemplated. In other words, the present methods were

---

[1] This is not always true. For example, if advertising costs are cut, sales may also drop and thus decrease profits. However, in this type of operation, which is an essential production operation, profits can be maximized by minimizing costs.

assumed to be correct.

As was stated before, the plans of U. S. Steel were to expand this plant's capacity to 3,000,000 ingot tons per year by converting all nine furnaces to a capacity of 400 tons. Since this expansion was planned to be completed within the year, a study conducted under present conditions would be of limited value to U. S. Steel. Therefore, it was decided to conduct the study assuming an annual output of 3,000,000 ingot tons.

Thus, the problem was defined as follows: Assuming an annual output of 3,000,000 ingot tons and assuming that the present methods are in fact, correct, how many ingot buggies should be available to result in the lowest total cost to the Corporation.

B. General Approach to the Problem

At this point it appeared as if there would be two primary costs associated with ingot buggies. One, the cost of having ingot buggies available, and two, the cost of not having ingot buggies available.

The cost of having ingot buggies available increases, of course, as the number of ingot buggies available increases. On the other hand, the cost of not having ingot buggies available decreases as the number of ingot buggies increases.

With no ingot buggies available, the cost of not having ingot buggies available would be prohibitively high since the whole plant operation would have to be shut down. But, as the number of ingot buggies available increases, this cost decreases until a point is reached where there are so many ingot buggies that some are always available when needed and this cost becomes zero. However, the cost of having ingot buggies available would probably be relatively high, and thus, the total cost of ingot buggies would not be zero.

The total cost can be determined by adding the cost of having an ingot buggy available to the cost of not having an ingot buggy available. The object of this study then is to determine the number of ingot buggies to have available that will result in the minimum total cost.

To help clarify the above discussion, the general cost curves have been plotted in Figure 4 (Appendix B). Even though these may not be the exact shapes of the curves, they do indicate the general approach to the problem.

What must now be determined are the exact shapes and values of these curves. This can be determined by varying the number of ingot buggies that are available. However, to do this with the ingot buggies themselves would be out of the question since production would be disrupted and the costs would be prohibitive. So what is needed is some other way of telling how the costs vary when the number of buggies available is varied. This can sometimes be done by constructing a mathematical model of the system.

C. Decision to Use Monte Carlo Techniques

The possibility of fitting a mathematical model to the system was investigated. However, it soon became apparent that any usable mathematical model fitted to the system would be so complex and unwielding that it would be difficult to work with. For instance, a brief look at the pouring operation should indicate the complexity of the situation.

The pouring operation is essentially a waiting line problem. There is the arrival of heats from nine furnaces, the arrival of ingot buggies to "service" the heat, the pouring platforms where the heats are serviced, and the servicing rate of pouring the heat.

The first difficulty in trying to fit a waiting line equation to this operation is that there are two different arrival rates, i.e., the arrival rate of heats and the arrival rate of ingot buggies, involved in the same operation. In addition, these arrival rates are interdependent. The arrival rate of ingot buggies is dependent upon the arrival rate of the heats, for this determines how many ingot buggies are in use at any given time. On the other hand, the arrival rate of heats is dependent upon the arrival rate of ingot buggies since no furnaces will be tapped if no ingot buggies are available.

The second difficulty is that the number of service channels does not remain constant. One of the pouring platforms is longer than the other two and can accommodate one long drag or two short ones. Thus the number of drags that can be serviced at any one time varies from three to four. This means, of course, that the number of service channels varies.

The third difficulty is the multiplicity of servicing rates. The servicing rate depends not only upon the speed with which the pouring operation is accomplished, but also upon the minimum metallurgical holding times specified for each ingot size and type of steel. Since the Metallurgical Department has specified five different minimum holding times, there would be at least five different servicing rates.

The above example, with two interdependent arrival rates, a variable number of service channels, and at least five different servicing rates, should indicate the complexity of any mathematical model that would approximate the pouring operation. In addition, mathematical models for the rest of the system would have to be determined.

It was soon realized that attempting to fit a workable mathematical model to the system would be almost impossible. Therefore, it was decided to use Monte Carlo techniques for the solution of the problem. With the use of these techniques the whole system could be simulated. The number of ingot buggies could then be varied to determine the change in costs.

The next step was collection and preparation of the data needed for a Monte Carlo simulation.

PREPARATION OF DATA

The data used in a systems study is, of course, of utmost importance. Without data that actually describes the system under study, a systems study is of no avail. However, obtaining accurate data is often very difficult. Usually data just does not exist and if it does, there is always the question of just what does it mean.

This chapter describes the preparation of data for the Monte Carlo simulation and thus, the system study. It tells from where the data was accumulated, what assumptions were made, and what manipulations were done with it.

The preparation of data was not only an important part of this study, but also the most time consuming, with about 80% of the total time devoted to the study used for data preparation.

A. Heat Size

The term heat is used to refer to a "batch" of steel made in the open hearth furnace. Heat size, then, refers to the weight in tons of one heat.

For purposes of this study, the heat size was defined to include all usable steel that was produced. That is, it excludes only slag and any steel wasted in pouring. The data was found by adding butt weight to the total ingot weight as found in the chronological heat reports maintained by the Open Hearth Division. The data collected covers a period from December 24, 1959, to January 20, 1960, for #2 furnace which has a capacity of 400 tons. At the time the data was collected, #2 furnace was the only furnace with a 400 ton capacity in operation.

The data collected was tabulated unto a frequency distribution (Table I)[1] and an average and standard deviation calculated (See Appendix C).

The average and standard deviations were calculated for use in the determination of the number of ingot buggies required for a drag of ingots. The original data was used for this calculation even though it would have been much easier to use the frequency distribution. However, the average and standard deviations were calculated before the frequency distribution had been tabulated.

B. Furnace Tap-to-Tap Time

The term furnace tap-to-tap time refers to the time elapsed from the tapping of one heat to the tapping of the next heat of one particular furnace.

Here again, the data of #2 furnace was used since it was the only 400 ton furnace in operation when the data was

---

[1] Upon looking at this frequency distribution as well as many others in the appendices, one may notice the apparent nonuniformity in the change of class intervals. When the frequency distributions were tabulated uniform cell intervals were used, but it was found that many of the frequency distributions had quite a number of cell intervals with no tally marks. These cell intervals were omitted from the frequency distributions appearing in the appendices to simplify the presentation of the data.

collected. This data was also taken from the chronological heat reports maintained by the Open Hearth Division.

However, since this furnace had just been rebuilt and was, in essence, completely new, the reported total tap-to-tap time was somewhat lower than furnaces which were in operation a longer period of time. The reason for this is that between each heat minor repairs, such as replacing loose bricks, have to be made to each furnace. The time to make such repairs, called the delay time, was naturally much shorter for #2 furnace since it had just been rebuilt.

The tap-to-tap time of #2 furnace had to be adjusted to a normal tap-to-tap time, since the tap-to-tap time of #2 furnace was to be used in the simulation study for all nine furnaces, and therefore, had to be a normal time. To make this adjustment, it was assumed that the normal delay time for the 400 ton furnace would be the same as the normal delay time of the 375 ton furnaces.

The method used to make this adjustment was as follows. From the chronological reports, the raw times (excludes delay time) of each heat were listed. (See Table II, Appendix D). The delay times of the other furnaces were taken from the chronological heat reports and also placed on a list and assigned numbers from zero to 299 (See Table III).[2] Then with the use of a random number table, a randon number between

---

[2] Only the number of every tenth delay time has been noted in Table III, however.

zero and 299 was selected. The delay time corresponding to this number was converted from minutes to decimal hours and added to the first listing of raw time in Table II to arrive at a total tap-to-tap time. This process was repeated until a delay time was added to all of the raw times.

These total tap-to-tap times were then converted from decimal hours to minutes (Table II) since it was decided to use the minute as a standard measure of time for the simulation study. These total tap-to-tap times were then tabulated into a frequency distribution for furnace tap-to-tap time (Table IV).

C. Furnace Life and Rebuild Time

The term furnace life refers to the time between rebuilds, i.e., when the furnace goes down for extended repairs, and the term rebuild time refers to the time required to make these repairs. Information on furnace life and rebuild time is necessary to consider furnace downtime in a simulation study.

U. S. Steel Corporation had very little information available on both furnace life and rebuild time. For furnace life they had data from which an average life could be calculated (See Appendix E) and for rebuild time they quoted an average of eleven days, which had been calculated just a few months before the study was conducted.

Since they had no information available on the variation of this data about the mean, other sources had to be utilized. Frequency distributions for both furnace life and rebuild time were found in "Applications of Monte Carlo Simulation in a Steel Company," a paper presented at the American Society for Quality Control in New York City, February 26-27, 1960, by S. Reed Calhoun of Lukens Steel Company.

However, Lukens Steel's averages were not the same as the averages calculated by U. S. Steel. Lukens Steel's average for furnace life was 110 days as opposed to U. S. Steel's calculated average of 128 days and for rebuild time was 12 days as opposed to 11 days quoted by U. S. Steel.

To arrive at frequency distributions for furnace life and rebuild time, two assumptions were made: (1) the averages calculated by U. S. Steel for furnace life and rebuild time were in fact the averages for their furnaces; and (2) the shape of the frequency distributions would be the same as Lukens Steel's distributions.

The method of adjusting Lukens Steel's distributions to fit the average of U. S. Steel was to shift Lukens Steel's distributions one cell interval. In the case of furnace life, the distribution was shifted up one cell interval to give an average of approximately 128 days (See Table V). In the case of rebuild time, the distribution was shifted down one cell interval to give an average of approximately 11 days, which is equal to U. S. Steel's average (See Table VII). These adjusted distributions were used as the frequency distributions for furnace life and rebuild time. (Tables VI and VIII).

Even though it had been decided to use the minute as the standard measure of time, it was decided in this case, however, to keep the distributions in days because of the cumbersome size of the data if it were converted to minutes. This data, which will not be used very often, can be converted to minutes as it is used.

D. Ingot Sizes Produced

The data of Table IX was taken directly from the "Ingot Tonnage per Month by Mold Size and Product" report and are the actual percentage produced in the year 1958.

No manipulation of this data was required to get it in the form it is in Table IX. However, for purposes of the simulation study, four ingot sizes were eliminated from the frequency distribution. These ingot sizes, 22 x 40 BED-OT, 22 x 50 BED-OT, 27 x 34 BED-BT, and 35 x 39 BED-BT, each were used less than one-half of one percent of the time. It was deicded to eliminate these four ingot sizes since it would simplify the systems study while not significantly affecting the results.

E. Holding Time

The source of this information was the Heat Transit Report of December, 1959 and January, 1960. The holding time was defined as the time elapsed from the tapping of the furnace to the release of the drag.

Holding time, as defined here, is dependent not only on the size of the ingot but also on the type of steel poured, i.e., rimmed, capped, semikilled, killed open and top, and killed hot top. However, since information was more readily available according to ingot size and since it was decided to follow ingot sizes through the system, the holding time data was accumulated by ingot sizes.

This data was then tabulated into a frequency distribution (See Appendix G). Classes were established every five minutes with class limits ranging plus or minus two from the mid-point, e.g., class limits of the cell interval with 75 as its mid-point would have class limits of 73 and 77. The frequency falling in each class was counted and the probability of occurrence and cumulative probability of occurrence were calculated for each class interval.

Differences in length of elapsed time due to different types of steel poured were thus considered, even though this influence cannot be isolated in the data. This influence can be seen though by observing the frequency distributions. For example, in the frequency distribution for holding time of ingot size 29 x 56 (Table XIV), one can note two distinct distributions, one centering about 75 minutes and the other centering about 160 minutes. We cannot tell from the frequency distribution the cause of this, but it is not needed for purposes of our analysis. The important thing is that all causes are considered even if the causes cannot be isolated.

F. Transit Time from Open Hearth to Stripper

This data was also taken from the Heat Transit Report from the months of December, 1959 and January, 1960. This frequency distribution (Table XX, Appendix H) is of the elapsed time from release at the open hearth to the time delivered at the stripper.

G. Stripping Time

The source of the original data was from the Heat Transit Report. This report listed the time the stripping operation started, the time it was finished, and the number of ingots stripped. The stripping time (start to finish) was divided by the number of ingots stripped to arrive at an average stripping time per ingot. These times per ingot were then tallied using cell intervals of 0.05 minutes and a frequency distribution tabulated.

The stripping time, however, is not only dependent upon the size of the ingot but also upon the type of mold used, i.e., Big End Down — Open Top, Big End Down — Bottle Top, and Big End Up — Closed Bottom. It was not easy to isolate this cause, but then it was not necessary to do so for purposes of analysis. The cause, however, is considered in the frequency distributions.

Of course, the type of mold used and ingot size are not the only factors influencing stripping time. Aside from these factors, the time required to strip a drag is not directly dependent upon the number of ingots stripped, but rather, is composed of a more or less constant time, i.e., the time requred to move a drag of cars into the stripper, and the variable time due to the number of ingots stripped. With the information available it was not possible to isolate this time, but again for the purpose of an overall systems study, it was not necessary.

One may notice that some of the frequency distributions include two different ingot sizes, e.g., the frequency distribution of Table XXII, Appendix I, is for ingot sizes 23 x 56 and 27 x 46. Individual frequency distributions were combined when the individual distributions were not significantly different. The primary reason for attempting to combine the distributions was that for some ingot sizes so few observations were available. For example, there were only six observations available for ingot size 25 x 80. Also, looking ahead to a possible computer application, it would save valuable storage space in the computer. The method used to determine whether the distributions were, in fact, significantly different was first by observation. If two distributions looked as if they were not significantly different, they were then checked by using Theory of Runs.

The specific method used was the one found in paragraph 16.4 of A. M. Moods book, <u>Introduction to the Theory of Statistics</u>. (New York: McGraw-Hill Company, Inc., 1950). This method was easy to use and it involved very few calculations. A Students t test could also have been used but that would have required the calculation of a standard deviation, a time consuming calculation which really was not required since the Theory of Runs would provide much the same results.

H. Transit Time from Stripper to Soaking Pits

The transit time from the stripper to the soaking pits was taken from the Heat Transit Report. The average time for January, 1960 was only 5.69 minutes. Since, in relation to the other times involved in the system, this time is so small, no frequency distribution was tabulated for this time. Rather, the average time of 5.69 minutes was used.

In addition, it was assumed that the time required to move a drag from the soaking pits to the stripper would be the same as the time required to move a drag from the stripper to the soaking pits. Therefore, the round-trip time between the stripper and the soaking pits was assumed to be 11.4 minutes.

I. Charging Time

Charging time, which is the time required to place an ingot into a soaking pit from a drag of ingot buggies, was not noted on the Heat Transit Report. Also, no other actual data was available for charging time. Therefore, as the only possible alternative, the engineering standard of 1.52 minutes per ingot was used.

J. Transit Time from Stripper to Mold Yard

No information was readily available for the time required to move a drag of ingot buggies from the stripper to the mold yard. Since the mold yard is in the same building as the open hearths, the distance covered and the tracks used from the stripper to the mold yard are the same as from the open hearth to the stripper. Therefore, the transit time from the stripper to the mold yard was assumed to be the same as the transit time from the open hearths to the stripper. Thus, the frequency distribution of Table XX was also used for the transit time from the stripper to the mold yard.

K. Reconditioning Time

No actual data was available for reconditioning time, which is the time required to coat the molds and clean the drag before it is used for the next heat.

The only information available were the estimates of a foreman in the open hearth and of an industrial engineer. Even though they were interviewed separately, their estimates for reconditioning time were the same. Their estimates were as follows: The minimum reconditioning time is one hour and the maximum is three and one-half hours with two hours being the most usual time.

With this information to go on, a normal curve skewed to the right was fitted to these parameters, with two hours taken as the mode of the distribution rather than the average. The curve was then tabulated into a frequency distribution for reconditioning time. (Table XXVIII).

L. Number of Ingot Buggies Inoperative

The source of data for ingot buggies inoperative was the Stool Buggy Report of the plant's Rolling Division. The data from this report was grouped according to the four primary reasons for an ingot buggy to be inoperative. That is, (1) it is being used to transport stickers, (2) it is being used as a shop buggy, (3) it is being used to hold cold steel, or (4) it is out for repairs and maintenance.

This data was accumulated by a form of work sampling. Each morning at eight o'clock, a simultaneous count of the cars and their use was taken in all areas of the system. The data from each observation was then compiled to form this report.

This data is thus biased by the fact that the observations were always taken at eight o'clock. If the time of observation had been selected randomly, average conditions would have been more likely observed. However, this was the only data that was available and it was used to tabulate the frequency distributions for the four classes of ingot buggies inoperative. (Tables XXIX thru XXXII).

However, this data did not break down these categories into B and C type buggies. Therefore, an assumption had to be made so that the number of buggies inoperative could be apportioned between the two types. The assumption was made that they would be apportioned according to the percentage of each type available. That is, since 83-1/2% of the buggies available were type B buggies and 16-1/2% type C buggies,[3] 83-1/2% of the number of buggies inoperative were assumed to be type B buggies and 16-1/2% type C buggies.

M. Calculation for Size of Drag

The number of ingot buggies needed for each ingot size was calculated by first dividing the maximum heat size by the average weight of the ingot to find the number of ingots. The total number of ingots required was then divided by the number of ingots that can be placed on one ingot buggy to find the number of ingot buggies required. To this was added a trailer car, which is an extra ingot buggy used to carry the trailer ingots.

The maximum heat size was taken to be the plus three sigma limit of the heat size distribution, while the average ingot weight was taken from Table XXXIII.[4] The number of ingots that can be placed on a car depends on whether the ingot requires a B or C type stool (Table XXXIII). With a B type stool, four ingots can be placed on one ingot buggy and with a C type, two ingots. To the calculated number, one extra ingot buggy was added to carry the trailer ingots.

---

[3] These percentages were calculated from figures taken from the Stool Buggy Reports.

[4] These average ingot weights are average weights as calculated by U. S. Steel and were taken from the "Ingot Tonnage per Month by Mold Size and Product" report of the Steel Producing Division.

(See Appendix L). The results of these calculations are listed in tabular form in Table XXXIV.

This method of calculation differs from the method used by U. S. Steel. They use the average heat size instead of the maximum and add two extra ingot buggies, one with regular size molds and the other with trailer ingots, instead of only one extra buggy. However, the results are about the same with the maximum difference being only one car for the smallest size ingot.

N. <u>Costs of Having Ingot Buggies Available</u>

There are two primary costs associated with having ingot buggies available for use at the plant. They are (1) the cost of purchasing the ingot buggies, and (2) the cost of repairing and maintaining them once purchased.

The purchase price of an ingot buggy is $12,000. To this should be added the cost of shipment, taxes, the cost of negotiating the purchase, etc. However, these costs were not readily available and were therefore omitted from the analysis.

To get this cost on a yearly basis, some idea of the useful life of an ingot buggy should be known. When this study was conducted, the plant had only been in operation for approximately six years and no actual data was available as the useful life of an ingot buggy. However, the Engineering Department estimated that an ingot buggy should be usable for at least twenty years. Since no actual data was available it was assumed that this figure was correct.

Therefore, the cost of purchasing an ingot buggy taken on a yearly basis is $600 ($12,000/20 years).

In addition to this raw figure, the Corporation's yearly cost of capital should be added. For instance, if the company is making 15% on their invested capital, a yearly charge of 15% or $90 should be added to the $600 raw figure. Also, any personal property taxes and insurance charges should be added. Since this information was not disclosed, these additional costs were not added. The yearly cost of acquisition was thus assumed to be $600.

The repair and maintenance costs for ingot buggies were taken from the Departmental Cost Reports for a period of one year and were summarized by month. (See Table XXXV, Appendix M). The total monthly costs include not only direct labor and direct materials but also all overhead expenses. Included in the overhead were indirect materials, all employee benefits, i.e., social security, pensions, insurance, and supplementary unemployment benefits, General Headquarter's expense, and depreciation and property taxes on the repair facilities.

The predominant type of damage which requires repairs is done to an ingot buggy in the pouring operation. Molten steel is accidentally poured in either its coupler or its wheels, thus "freezing" these moving parts. Thus, repairs are dependent not upon how many ingot buggies are available but upon how many times they have been exposed to the pouring operation. Since the number of times they have been exposed to the pouring operation is in turn dependent upon the number of tons produced, the repairs and thus repair costs should be dependent also upon the number of tons produced. In other words, the repair cost per ton produced should be a constant.

This cost was calculated by month in Table XXXV and on a monthly basis it does vary. However, it was assumed that if this were computed on a yearly basis the monthly variations would cancel out the repair cost per ton of steel produced would be more or less constant. Thus, the twelve months' average figure of $0.0534 per ton was taken to be the ingot buggy repair cost per ton of steel produced.

The costs of having ingot buggies available have been plotted in Figure 5 (Appendix M). This curve consists of the two primary costs of having ingot buggies available, i.e., the cost of repairs and maintenance and the cost of acquisition. Since the cost of repairs and maintenance varies with the amount of steel produced and not with the number of ingot buggies available, it is shown as a constant, or fixed cost, in Figure 5. The value of the repair and maintenance costs was derived by multiplying the projected output of 3,000,000 ingot tons by the average cost of $0.0534 per ton and it amounted to $160,000 per year. The cost of acquisition, which is a variable cost and depends, of course, upon the number of ingot buggies available, is computed at $600 per buggy.

Thus the total cost of having an ingot buggy available is $600 times the number of ingot buggies available plus $160,000. In equation form this would be:

$$TC = \$600N + \$160,000$$

where TC is the total cost and N is the number of ingot buggies available.

C. Cost of Not Having Ingot Buggies Available

Of course, if no ingot buggies were available, the cost would be prohibitive since no steel could be produced. However, moving into the range of a practical number of ingot buggies available, two primary costs are associated with not having ingot buggies available when needed. One is the cost of not having ingot buggies available when a furnace is ready to be tapped and the other is the cost of not having buggies available when a drag of ingots is ready to be stripped.

If a drag of ingot buggies is not available when a furnace is ready to be tapped, the steel is kept in the furnace until a drag is available. However, a heat of steel cannot be kept in the furnace indefinitely and eventually it would have to be tapped to the ground. Also, there are some special circumstances, such as burning brick, where the steel would have to be removed at once. But assuming normal conditions and a practical waiting time, the cost of not having ingot buggies available when a furnace is ready to be tapped is the cost of holding the heat in the furnace.

The cost of holding a heat in a furnace is equal to the cost of operating the furnace the extra time plus the loss in profits due to the loss in production caused by the delay. This cost has been calculated in Appendix N and is equal to $453 per hour of delay. The costs used in this calculation were obtained from the Open Hearth Division Office.

The other cost of not having ingot buggies available is the cost incurred when a drag of ingots cannot be stripped because a drag of empty ingot buggies is not available to strip on. The stripping mill will do everything that it can to strip ingots and move them into the soaking pits as long as there is pit room available. If a drag of empty ingot buggies is not available, the stripping mill will strip the ingots and place the empty molds on the ground. The only place on the ground where they can set the empty molds is on a railroad track. Since the stripping mill will only tie up one of their four tracks with empty molds, only one drag of ingots can be stripped to the ground.[5] However, it seems very unlikely that more room than this will be needed since an empty drag will be available as soon as these ingots are charged.

---

5. In addition, the stripping mill can place up to 10 molds on the ground off the tracks. However, this is not enough room to strip a whole drag of ingot buggies. Also, this room may be needed to strip some molds to the ground when the drag to be stripped has more cars than the drag on which the empty molds will be placed.

Extra costs are incurred by stripping to the ground because the cranes have to handle the molds one extra time. However, the stripping mill has excess capacity, setting idle part of the day. The most significant stripping cost is labor and in a practical range of operations is a fixed cost. That is, the men have to be paid whether they are working or not. The variable operating costs, such as electricity and more maintenance for the overhead crane, are insignificant when compared with the labor costs. Therefore, since there is no significant incremental cost involved, the cost of stripping to the ground was not considered.

If the ingots cannot be stripped at all, two costs are incurred. One is the cost of possible mill downtime because no ingots of the desired size are available for rolling and the other is the cost of losing heat to the atmosphere.

The cost of mill downtime was not considered because it was beyond the scope of this study. Mill downtime may be caused by many other things besides a shortage of ingot buggies. For example, even though the ingot buggies may be bringing ingots to the soaking pits, they may be the wrong size, the pits may be filled, or the soaking pit crane may be out of operation. Therefore, to include the cost of mill downtime caused by not having ingot buggies available when needed, the simulation study would have had to be extended to include the soaking pit operation and the operation of the rolling mill. Since this was beyond the scope of the study and since no rule of thumb cost figures were readily available, the cost of mill downtime was not considered.

However, the cost of losing heat to the atmosphere was considered. The longer ingots remain in the atmosphere, the more heat is lost to the atmosphere and the more heat is required to bring them back up to rolling temperature in the soaking pits. The cost of heating an ingot in the soaking pits for each hour delay was calculated. (See Appendix N). The number of pit heating hours required for each hour of delay was taken from a graph supplied by the Metallurgical Department. The figure for size 32 x 32 ingot was used since this is the size ingot most frequently used. The cost figures were supplied by the Rolling Division Office and include only the variable cost of operating the soaking pits. That is, only the true incremental costs and no fixed costs were considered.

The calculated incremental cost of heating an ingot in the soaking pits was $0.012 per hour of delay. Assuming a maximum drag size of 64 ingots the cost per drag would amount to a maximum of only $0.77 per hour, hardly a significant cost when compared to $453 per hour for holding a heat in the furnace. Thus, the most significant cost of not having ingot buggies available when needed is the cost of holding a heat in a furnace.

SOLUTION OF THE PROBLEM

Once the data was collected, it was realized that doing a simulation of the system by hand would take a prohibitive amount of time. Therefore, it was decided to use the LGP-30, an electronic computer available in the Industrial Engineering Department at Lehigh University, for the simulation of the system. The next step then was programming the problem for the computer.

A. Assumptions

Before the problem could be programmed, additional assumptions[1] had to be made and decision rules defined.

First, let us review the assumptions made in defining the problem. They were (1) that plant capacity was equal to 3,000,000 ingot tons per year, and (2) that the present methods were, in fact, correct. It was seen at this time that an additional assumption had to be made. Since the object of the study is to measure the effect of ingot buggies on the system, the rest of the system was assumed to have unlimited capacity. For instance, heats may not be poured not only because no ingot buggies are available but also because there is no pouring platform available. Since we

---

[1] We are now concerned with the basic and logical assumption underlying the solution of the problem itself and are now concerned with the assumptions concerning the preparation of data which were explained in the previous chapter.

are studying the effect of ingot buggies and not the effect of a limited number of pouring platforms, it must be assumed that there is always a pouring platform available when one is needed. Therefore, the assumption of unlimited capacity had to be assumed for the rest of the system, i.e., pouring platforms, soaking pit capacity, locomotives, reconditioning capacity, track capacity, etc. This may appear as if a lot has been assumed, but one must remember that the effect of ingot buggies is being studied and not the effect of these auxillary parts of the system.

The above assumption is a basic assumption upon which the solution of the whole problem rests. It should have been made when the problem was defined but it was not realized that it had to be made until the programming of the problem was begun. Following are assumptions which are not basic to the solution of the problem itself but which were made so that the data could be manipulated by the computer.

Each furnace was given two clocks. One clock to keep track of the time when a furnace is to be tapped and the other clock, the time when a furnace will go down for rebuilding. In addition, a clock is used to record the number of days elapsed. These clocks, of course, are not actual clocks, but rather storage locations in the computer.

It was assumed that there would be two pools (similar to motor pools) for ingot buggies. One is at the open hearth, and is called the open hearth pool, and the other is at the stripper, and is called the stripper pool.[2] In addition to these pools, two waiting lists are maintained. One is a list of furnaces waiting to be tapped. If a furnace is ready to be tapped and no buggies are available, the furnace is placed on this list and given top priority for the next cars arriving. The other list (actually two lists - one for each type of ingot buggy) is a list of drags waiting to be stripped. If a drag arrives at the stripper and cannot be stripped, it is put on this list and given top priority for stripping.

Another assumption made was that the number of ingot buggies inoperative would be adjusted only once a day - i.e., at the start of each day. However, there was really no choice in this matter since data was available only on a daily basis.

The rest of the assumptions were made primarily in the defining of decision rules used. Most of the decision rules were already clearly defined in the actual system, but some were nebulous and had to be more clearly defined, and thus assumptions made. Explicit definition of all decision rules is mandatory for computer application since the computer has no intuitive judgment. Instead of listing these decision rules separately, they will be incorporated into the

---

[2] There are actually four pools instead of two. Each pool is subdivided into two pools - one for each type of ingot buggy.

discussion of the flow chart since many were made concurrently with its design. Also, it is hoped that such a presentation will be more meaningful to the reader.

B. Programming the Problem

Flow charting was the first step in programming the problem. The general flow charts, which are really diagrams of the logical steps to be performed, are included in Appendix O. These flow charts stress the logic of the programs and not the arithmetical manipulations. The flow charts show two groups of decisions that the computer must make. One group starts with the selection of the smallest clock and the other with the "arrival of the drag at the stripper."

The first group of decisions starts with the selection of the smallest clock. After the smallest clock is selected, it is determined what kind of clock it is. If it is a "rebuild" clock, the time has come whan a furnace will go down for rebuilding. The time required to rebuild the furnace is determined and the furnace is taken out of operation for that length of time. The rebuild clock is then reset to the time the furnace will next go down for repairs.

If the smallest clock is a heat clock, it must be determined whether or not a day has gone by. If it is the end of a day, the next decision to be made is whether or not it is the end of the period; for example, a month. If it is the end of the period, the results of the simulation are printed out and the computer stops. If it is the end of a day and the period has not expired, the number of ingot buggies inoperative is adjusted, the day clock is updated, and the computer returns to again select the smallest clock.

If the smallest clock is a heat clock and it is not yet the end of a day, the first step is to replace the ingot buggies no longer in use into the open hearth pool. The next step is to determine if any furnaces are waiting to be tapped. If there are, they are given top priority and handled first. But before they are handled, the computer determines if there are enough ingot buggies available to handle the heat. If there are not enough available, the computer will stop, for either some mistake has been made or the system has broken down. If there are enough cars available, the delay cost is calculated, the furnace tapped, and a drag of ingot buggies put in the normal cycle of operation. Its holding time is then determined and after being held for this time, the drag is sent to the stripper.

If there are no furnaces waiting to be tapped, the number and type of ingot buggies for the furnace to be tapped are determined. The computer then determines if there are enough, the furnace is added to the furnace waiting list, its clock reset, and the next smallest clock selected. If there are enough cars available, the furnace is tapped and a drag of ingot buggies is put into the normal cycle of operation. Its holding time is determined and after being held for this time, it is sent to the stripper.

When the drag arrives at the stripper, the other group of logical decisions is made before it proceeds. The first one is to determine if there are any drags waiting to be stripped. If there are and if there is a drag of buggies available to strip on, the drag waiting will first be stripped. The delay cost is determined, the drag of ingots is sent to the soaking pits, then on to the stripper pool, and the drag of molds is sent back to the mold yard. This cycle continues until there are no drags left waiting to be stripped or until no drags are available to strip on. If there are no drags available to strip on, the drag waiting stays on the waiting list and the drag that just arrived is also put on since obviously there will be no drag available for it to strip on either.

If there are no drags waiting to be stripped, the computer next determines if there is a drag of molds setting on the ground. If there is and if there is also a drag of empty buggies available to put them on, they are sent back to the mold yard.

After the above two areas; that is, drags waiting to be stripped and molds setting on the ground, have been taken care of, the normal cycle of operation continues. The computer now determines if there is a drag of empty buggies available to strip the drag that just arrived. If there is not, next it determines if it can set the molds on the ground. If it cannot, it puts the drag on the waiting list for drags to be stripped and returns to the beginning of the program and selects the next smallest clock. If it can strip to the ground, it will. After stripping, it sends the drag of ingots to the soaking pits and then on to the stripper pool. The computer then returns to the beginning of the program and selects the next smallest clock.

If there is a drag of ingots available to strip on, the drag that just arrived is stripped directly to the other drag, the drag of molds is sent back to the mold yard, the drag of ingots is sent to the soaking pits, and then on to the stripper pool. The computer then returns to the beginning of the program and selects the next smallest clock.

Of course, the general flow charts and the above description are greatly simplified; but then, they are not intended to give detail. Their purpose is to present the underlying logic of the computer program.

After completion of the general flow charts, detailed flow charts were drawn. From these the program actually read into the computer was written. This program was written in ACT, which stands for Automatic Compiler and Translator. That is, the program was written essentially in algebra and the computer, by using ACT, converted it to a hexadecimal program, which is in machine language.

The simulation program, as originally written, utilized thirty-six frequency distributions to simulate the system. Briefly, the program utilized them as follows. For instance, if the program called for the transit time for the open hearth to the stripper, the computer (as programmed) would generate a random number, go to the transit time frequency distribution which was stored in the computer, and select the value corresponding to the random number generated. To generate one month's data, it was estimated that the computer program (originally written) would take approximately 896 random samples from these thirty-six frequency distributions.

C. Problems Encountered in Programming

Even though from forty to fifty hours were spent programming the problem and preparing the paper tapes, the program was far from "operational." Approximately fifty more hours had to be spent before the program was debugged and ready for use. Just on compiling alone, twenty-four hours were spent before a successful compiling run was completed.

The basic cause of most of the difficulties was inadequate storage space in the computer. It was realized from the very beginning that the computer's storage capacity was limited and steps were taken to save storage space. All frequency distributions were reduced from one hundred to fifty cells. This alone saved 1850 storage spaces. In addition, most of the ACT subroutines were eliminated and the whole ACT program shifted down five tracks, thus saving another 832 storage spaces. Also, the data input routine for the fixed data was eliminated from the ACT program since this data could very easily be read into the computer by using a simple decimal input routine, and more space could be saved.

However, two-thirds of the way through the first compiling run all of the available space was exhausted. More space had to be saved. It was then decided to eliminate the thirteen frequency distributions for stripping time and substitute the engineering standard for this time. This saved an additional 650 storage spaces.

The next time the compiling run was tried enough space was available; but through a combination of errors in the compiling program and in the simulation program itself, the resulting hexadecimal program was worthless. The third try was also unsuccessful because of errors in the compiling program.[3] On the fourth try, the compiling run was successful. With each compiling run taking approximately three hours, plus the time required to detect the errors and to read in the appropriate input routines, the total time spent on the computer just for compiling alone, was twenty-four hours. This did not include time required for debugging the program itself.

The problems mentioned above were just the major problems encountered. Other problems were encountered because of minor mistakes in the simulation program itself and because of the inability of ACT to perform certain computer

---

3. One of the reasons for all the errors in the ACT compiling program was the changes made to it so that more room would be available for the simulation program.

manipulations. However, all of these minor problems, even though they were time consuming to solve, presented no special difficulties.

The ACT program, as finally compiled,[4] is given in Appendix P. In addition, definitions of the symbols used in the ACT program have been included in Appendix Q. These definitions include only the significant symbols used and do not include symbols used for temporary storage spaces and for counters.

The data, as previously tabulated, had to modified before it was ready for use by the computer. As was stated before, all frequency distributions were reduced from one hundred to fifty cells and, of course, all decimal points were eliminated. The data, as actually read into the computer, is given in Appendix R.

D. Results

Because of the excessive amount of time required to program this problem, and also because of some computer down-time, sufficient time to generate data was not available. However, it was shown that the material handling system which was studied could be simulated by using Monte Carlo techniques and that this simulation could be programmed for the LGP-30 electronic computer.

---

[4] For completeness, an input for the fixed data has been included in the ACT program in the appendix even though it was not compiled but rather written in decimal form to save computer space.

CONCLUSIONS

Looking beyond the specific results of the problem, the following conclusions were arrived at.

Monte Carlo techniques can be a valuable tool for conducting system studies. Since workable mathematical models are often not derivable, and since experimental techniques cannot be used on a whole industrial system because of prohibitive costs, Monte Carlo simulation of the system is often the only alternative for solution of the problem.

However, when using Monte Carlo techniques the following points should not be overlooked.

1. Understand completely the physical operation of the system before proceeding further.
2. Define the problem as specifically as possible.
3. Decide what data is needed before attempting to gather it.
4. If a computer application is planned, know the limitations and capabilities of the computer before programming the problem and preparing the data.

Of the four steps listed above, only one was done adequately in this study and that was step #2. Much time was wasted in this study because (1) a basic concept of the system studied was not understood at the beginning of the study; i.e., the basic unit for handling ingots and molds was thought to be the ingot buggy instead of a drag of ingot buggies, (2) unnecessary data was collected and unnecessary calculations performed, and (3) the limitations of the computer which was used were not fully understood before programming the problem and preparing the data were begun. This resulted in a number of revisions to the program and the preparation of much unusable data. If these steps had been taken the time required to complete the study could have been reduced by at least 25%.

APPENDIX A

Glossary

GLOSSARY

B Car	-	An ingot buggy with a type B stool.
Butt	-	An ingot too short to be rolled.
Car	-	An ingot buggy.
C Car	-	An ingot buggy with a type C stool.
Charging	-	Placing ingots in the soaking pits.
Cold Steel	-	Ingots that have been allowed to become cold.
Drag	-	A string of ingot buggies.
Furnace	-	An open hearth.
Heat	-	A batch of steel made in the open hearth.
Ingot	-	A piece of steel ranging from 22 x 40 x 80 inches up to 88 x 44 x 115 inches and from 7.42 tons to 17.90 tons.
Ingot Buggy	-	A specially built, standard gage railroad car used to transport ingots from the open hearth to the rolling mill.
Mold	-	Used to form ingots.
Open Hearth	-	Furnace used to make steel.
Rolling Mill	-	Mill where ingots are rolled into the finished product.
Shop Buggy	-	An ingot buggy used for spare parts.
Soaking Pits	-	Open-topped gas fired furnaces where ingots are brought to a uniform temperature before rolling.
Stickers	-	Ingots whose molds cannot be removed by the stripping crane.
Stool	-	A cast iron slab placed on an ingot buggy.
Stripper	-	Stripping mill.
Stripping	-	Removing the molds from ingots.
Stripping Mill	-	The building where molds are removed from the ingots.

GLOSSARY (Cont'd)

Tapping -	Removing steel from an open hearth.
Trailer Car -	An ingot buggy with trailer ingots placed at the end of a drag.
Trailer Ingot -	The smallest size ingot that can still be rolled used to prevent butts.

APPENDIX B

General Information

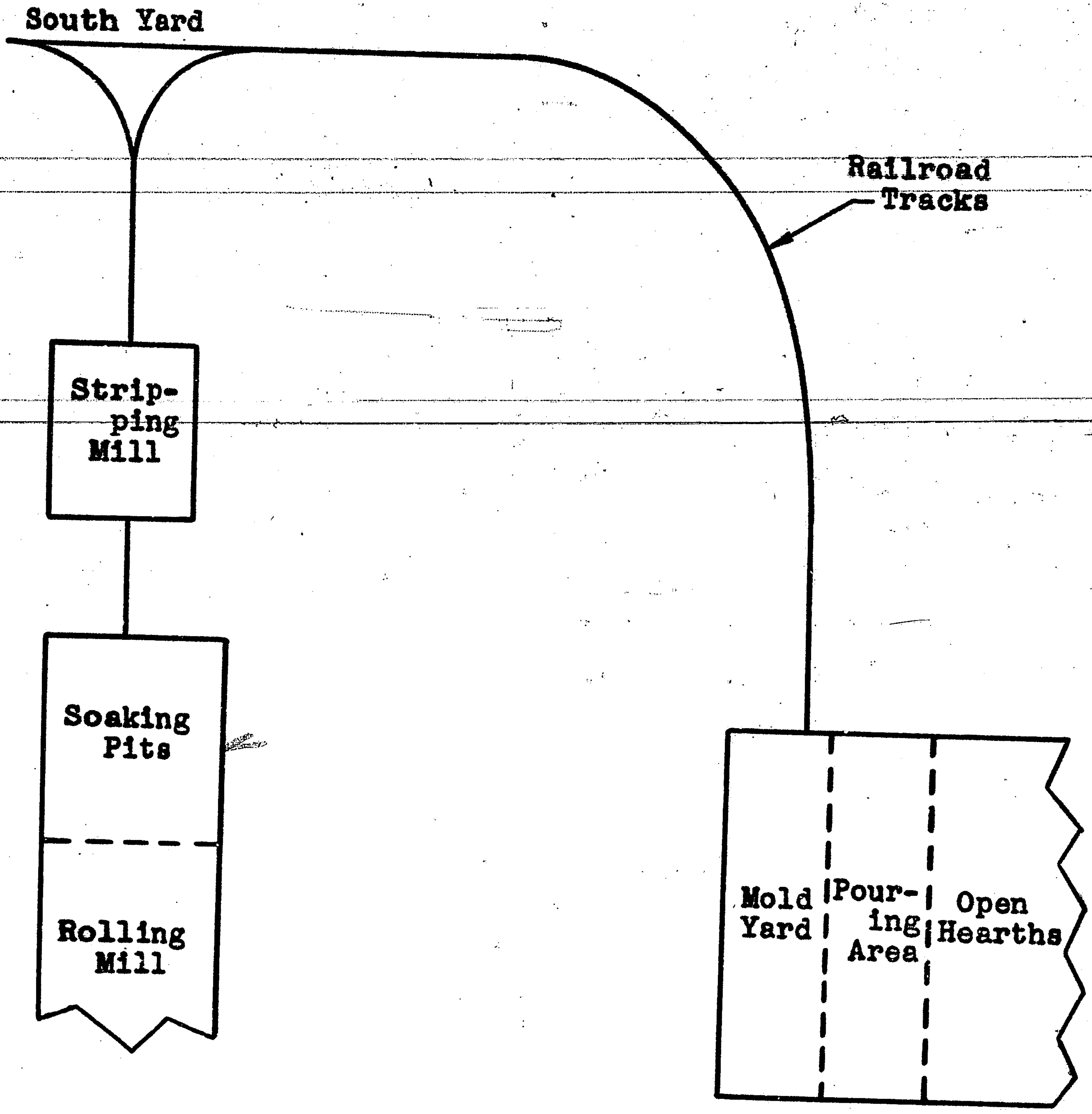


Figure 1
LAYOUT OF SYSTEM

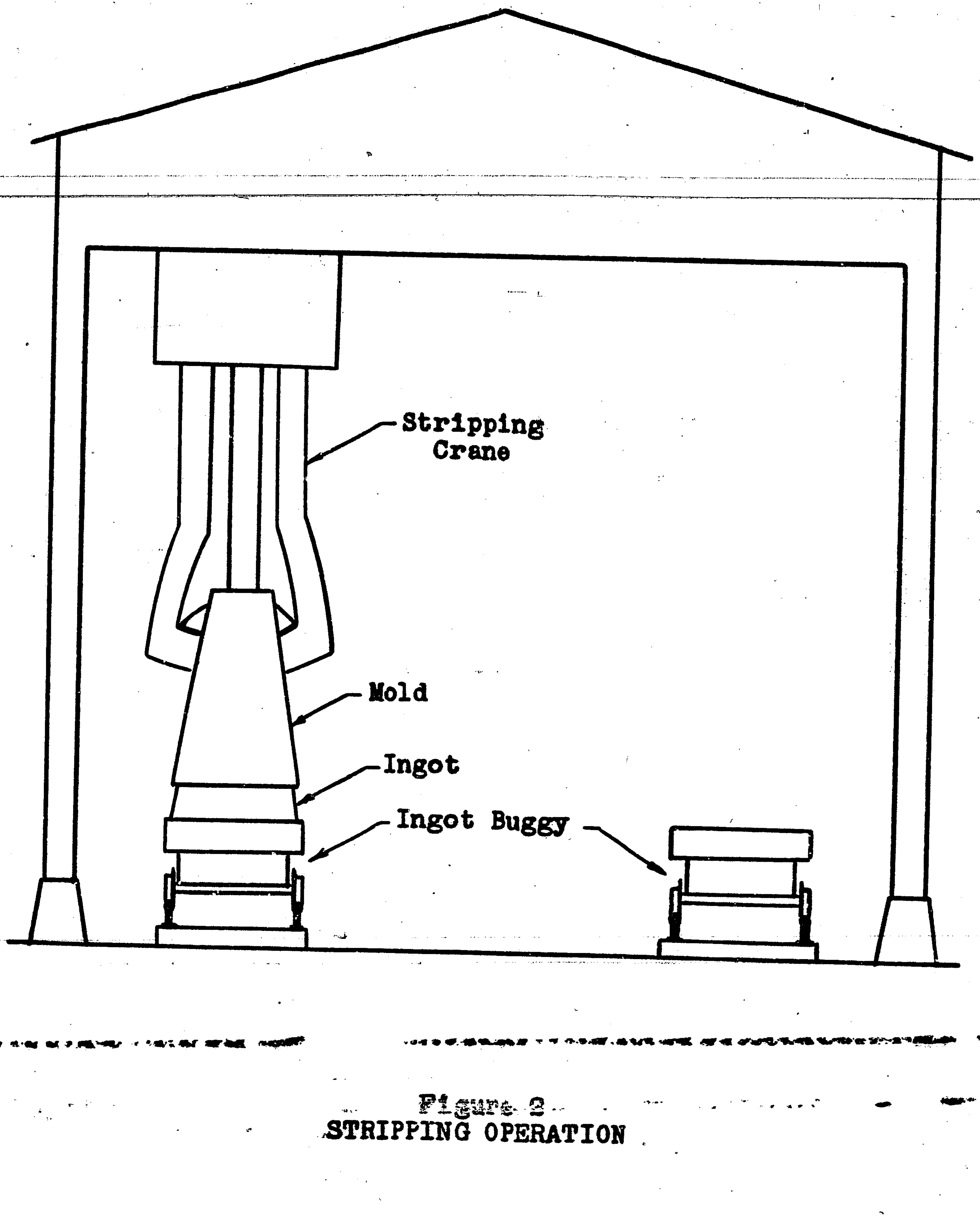


Figure 2
STRIPPING OPERATION

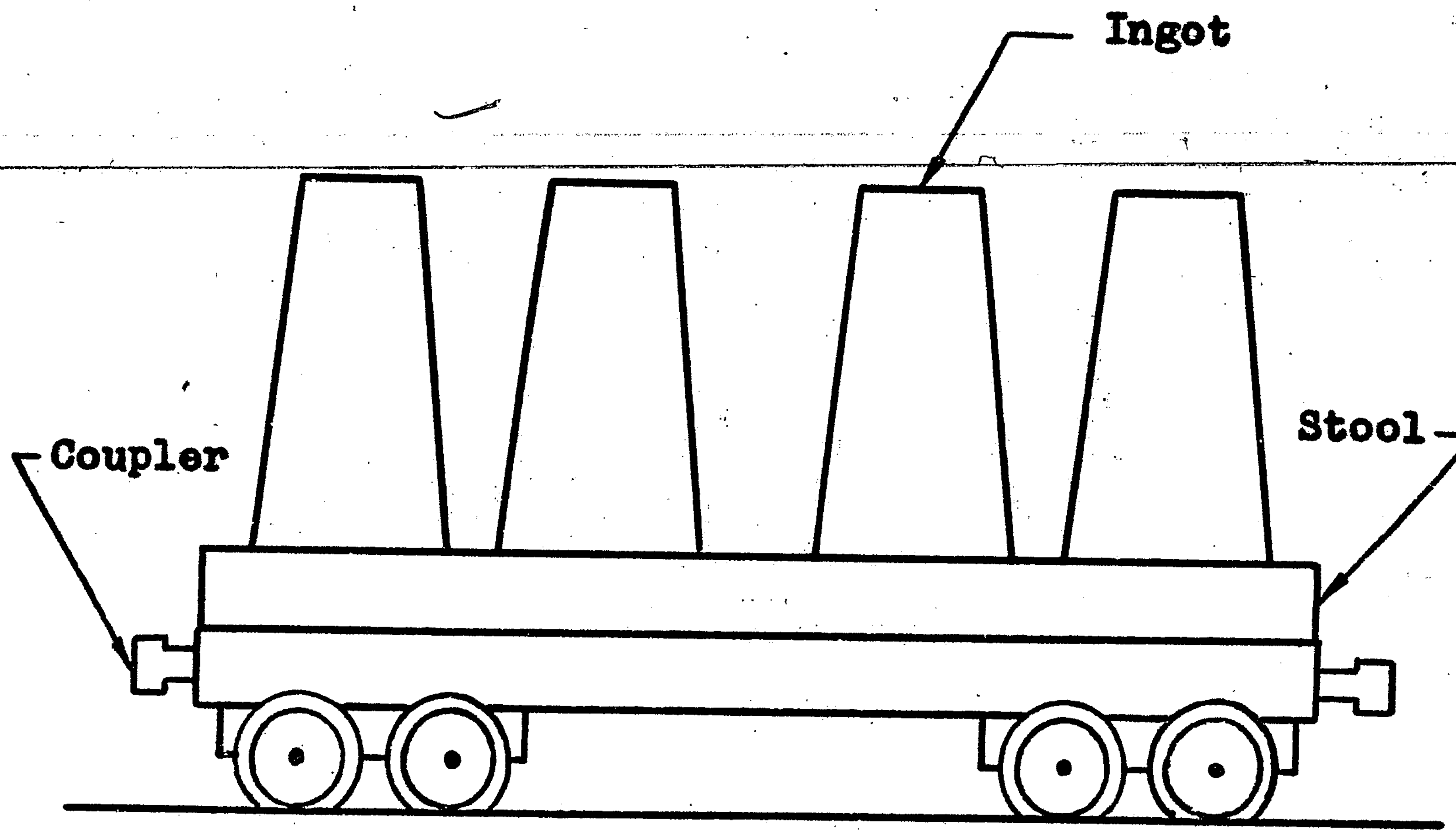


Figure 3
INGOT BUGGY

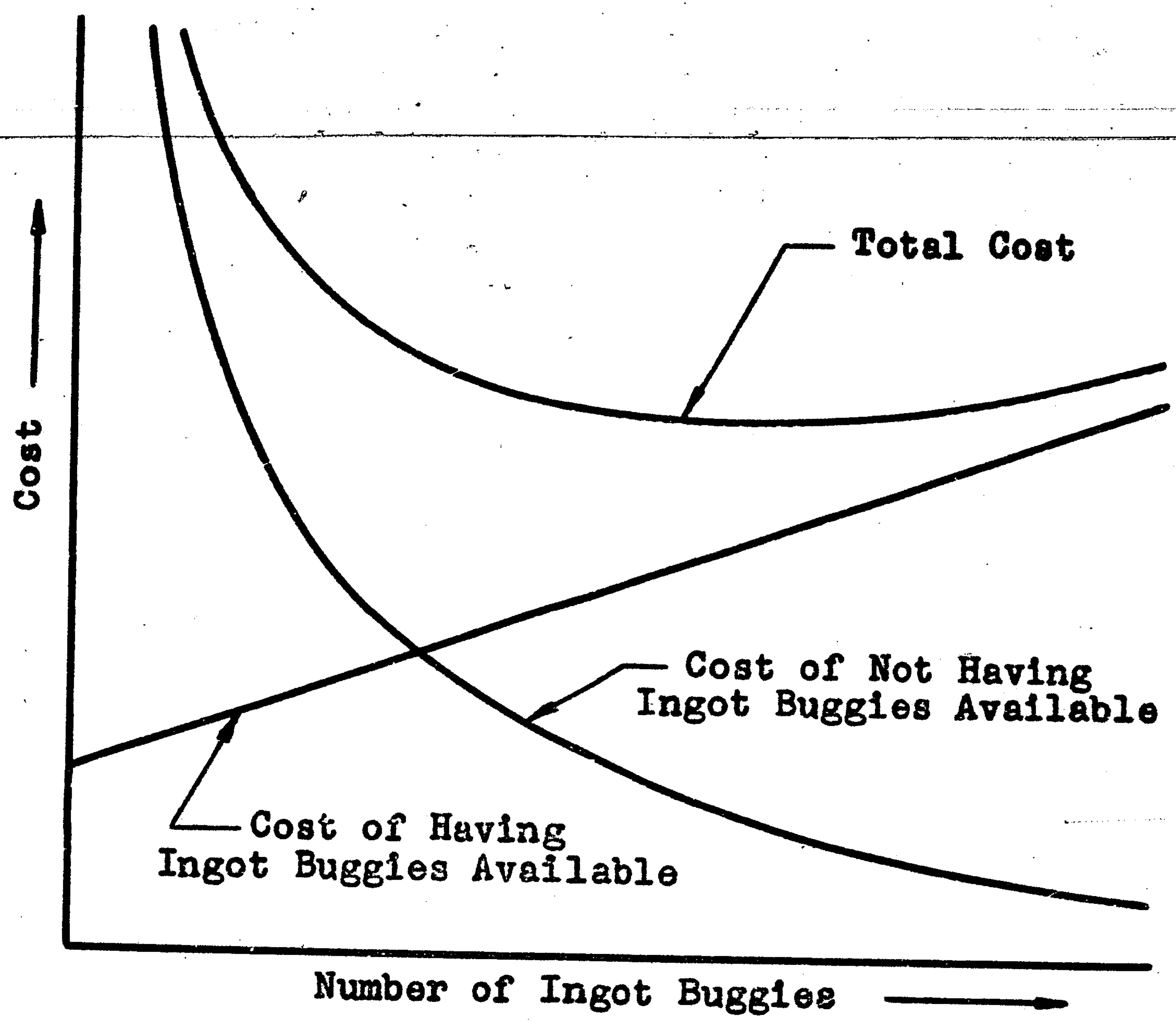


Figure 4
GENERAL COST CURVES

APPENDIX C

Frequency Distribution and Calculation for Standard Deviation of Heat Size for #2 Furnace

TABLE I

Frequency Distribution for Heat Size of #2 Furnace

Heat Size (Tons)	Frequency	Probability	Cumulative Probability
288	1	.0102	.0102
352	1	.0102	.0204
364	1	.0102	.0306
368	1	.0102	.0408
370	1	.0102	.0510
380	1	.0102	.0612
382	3	.0306	.0918
384	1	.0102	.1020
386	1	.0102	.1122
388	1	.0102	.1224
390	5	.0510	.1734
392	2	.0204	.1938
394	2	.0204	.2142
396	1	.0102	.2244
398	5	.0510	.2754
400	6	.0612	.3366
402	4	.0408	.3774
404	5	.0510	.4284
406	4	.0408	.4692
408	7	.0714	.5406
410	9	.0918	.6324
412	5	.0510	.6834
414	6	.0612	.7446
418	4	.0408	.8262
420	4	.0408	.8670
422	1	.0102	.8772
424	3	.0306	.9078
426	3	.0306	.9384
428	1	.0102	.9486
430	1	.0102	.9588
434	1	.0102	.9690
436	1	.0102	.9792
442	1	.0102	.9894
444	1	.0102	.9996

Calculation for Average and Standard Deviation of Heat Size for #2 Furnace

$$\bar{X} = X_o + \sum \frac{X_1 - X_o}{n}$$

$$= 400 + \frac{428.8}{98}$$

$$= 404.4 \text{ tons}$$

$$s^2 = \frac{\Sigma(X_1 - X_o)^2}{n} - \left(\frac{\Sigma(X_1 - X_o)}{n} \right)$$

$$= \frac{39.907.2}{98} - \left(\frac{428.8}{98} \right)$$

$$= 407.22 - 19.36$$

$$= 387.86$$

$$s = 19.7 \text{ tons}$$

APPENDIX D

Adjustment of #2 Furnace

Tap-to-Tap Time and Frequency

Distribution for Furnace Tap-to-Tap Time

TABLE II

Accumulated Data and Adjustment of Tap-to-Tap Time of #2 Furnace

Raw Time (Decimal Hrs.)	Delay Time (Decimal Hrs.)	Total Tap-to-Tap (Decimal Hrs.)	Total Tap-to-Tap (Minutes)
7.98	.42	8.40	504
6.92	1.00	7.92	475
7.93	1.00	8.83	530
8.62	.67	9.29	557
6.75	.67	7.42	445
8.83	2.08	10.91	654
6.67	.08	6.75	405
7.00	.83	7.83	470
7.67	2.42	10.09	605
7.08	.42	7.50	450
7.47	.50	7.97	478
6.92	.67	7.59	455
7.08	2.83	9.91	595
7.33	.67	8.00	480
8.33	1.37	9.70	582
7.58	.50	8.08	485
7.53	.67	8.20	492
7.25	.33	7.58	455
7.33	.50	7.83	470
6.92	.33	7.25	435
8.58	1.05	9.63	578
8.75	.50	9.25	555
7.17	.75	7.92	475
7.92	.38	8.30	498
6.83	.42	7.25	435
9.08	.58	9.66	580
8.17	1.58	9.75	585
8.17	.78	8.95	537
7.75	.25	8.00	480
7.70	.75	8.45	507
7.33	1.05	8.38	503
7.58	.50	8.08	485
7.67	.42	8.09	485
7.08	.33	7.41	445
7.17	.75	7.92	475
8.83	.50	9.33	560
7.08	1.05	8.13	488
8.42	2.24	10.67	640
7.67	.58	8.25	495

TABLE II - Continued

Raw Time (Decimal Hrs.)	Delay Time (Decimal Hrs.)	Total Tap-to-Tap (Decimal Hrs.)	Total Tap-to-Tap (Minutes)
6.67	5.50	12.17	730
7.17	.42	7.59	455
7.67	.50	8.17	490
7.00	2.00	9.00	540
6.83	1.58	8.41	505
6.67	.75	7.42	445
7.08	.67	7.75	465
6.58	.47	7.05	423
7.58	1.08	8.66	520
7.85	.42	8.27	496
6.82	.67	7.49	449
8.00	.33	8.33	500
7.00	.58	7.58	455
7.28	.42	7.70	462
7.08	.83	7.91	475
6.92	.58	7.50	450
7.17	.47	7.64	458
7.33	.33	7.66	460
6.17	.33	6.50	390
7.75	.28	8.03	482
7.67	.83	8.50	510
7.42	.33	7.75	465
8.00	1.22	9.22	553
7.58	.47	8.05	483
7.58	1.58	9.16	550
7.37	.45	7.82	469
8.25	.67	8.92	535
7.92	1.05	8.97	538
8.17	4.08	12.25	735
7.50	.83	8.33	500
7.88	.33	8.21	493
7.00	.33	7.33	440
7.33	.50	7.83	470
6.67	.42	7.09	425
7.17	.33	7.50	450
7.37	.92	8.29	497
6.13	.33	6.46	388
7.92	.67	8.59	515
8.33	6.42	14.75	885
6.55	.33	6.88	413
5.83	.83	6.66	400
8.33	.78	9.11	547
6.50	.50	7.00	420
6.83	1.33	8.16	490

TABLE II - Continued

Raw Time (Decimal Hrs.)	Delay Time (Decimal Hrs.)	Total Tap-to-Tap (Decimal Hrs.)	Total Tap-to-Tap (Minutes)
7.75	.83	8.58	515
7.77	.33	8.10	486
9.33	.33	9.66	580
6.50	1.67	8.17	490
7.40	.25	7.65	459
6.92	.33	7.25	435
7.00	.75	7.75	465
8.50	.58	9.08	545
7.20	1.33	8.53	512
9.42	.38	9.80	588
7.38	.83	8.21	493
6.37	.33	6.70	402
6.83	5.08	11.91	715
7.50	.75	8.25	495

TABLE III

Accumulated Data of Furnace Delay Time

Number	Delay Time (Minutes)	Number	Delay Time (Minutes)
#0	140	#40	35
	150		20
	50		20
	80		45
	25		30
	90		20
	95		385
	20		30
	360		20
	95		120
#10	20	#50	25
	140		75
	70		35
	30		30
	55		50
	35		20
	20		20
	35		20
	25		28
	30		20
#20	305	#60	40
	112		25
	28		63
	145		25
	20		60
	20		65
	20		25
	143		20
	45		25
	40		35
#30	20	#70	45
	20		20
	35		65
	35		110
	45		33
	15		25
	90		33
	165		145
	20		20
	20		25

TABLE III (Cont'd)

Number	Delay Time (Minutes)	Number	Delay Time (Minutes)
#80	45	#120	40
	145		18
	22		15
	15		45
	20		40
	30		15
	30		35
	30		20
	18		25
	35		100
#90	17	#130	80
	110		30
	82		22
	40		35
	47		40
	30		25
	60		88
	25		30
	20		40
	35		65
#100	40	#140	30
	80		90
	125		25
	25		20
	20		30
	20		125
	20		230
	20		33
	30		25
	27		28
#110	70	#150	20
	23		23
	30		20
	22		120
	20		20
	40		30
	25		155
	72		135
	53		245
	170		150

TABLE III (Cont'd)

Number	Delay Time (Minutes)	Number	Delay Time (Minutes)
#160	23	#200	115
	30		95
	17		60
	25		75
	17		20
	19		40
	25		27
	70		20
	40		35
	95		30
#170	07	#210	45
	35		05
	40		20
	45		80
	330		35
	20		35
	75		23
	20		20
	20		20
	28		20
#180	25	#220	20
	120		28
	20		20
	245		45
	30		30
	58		50
	25		35
	45		25
	18		80
	33		50
#190	95	#230	55
	20		40
	20		60
	95		15
	35		35
	15		55
	35		100
	35		25
	40		25
	55		15

TABLE III (Cont'd)

Number	Delay Time (Minutes)	Number	Delay Time (Minutes)
#240	17	#280	35
	22		20
	30		23
	50		150
	23		40
	40		60
	45		75
	40		30
	40		225
	95		40
#250	235	#290	30
	31		20
	35		22
	110		30
	96		25
	30		20
	40		75
	20		30
	25		25
	20	#299	20
#260	20		
	110		
	150		
	20		
	85		
	90		
	35		
	50		
	63		
	30		
#270	105		
	245		
	20		
	52		
	178		
	40		
	20		
	28		
	20		
	20		

TABLE IV

Frequency Distribution for Furnace Tap-to-Tap Time

Minutes	Frequency	Probability	Cumulative Probability
390	2	.0206	.0206
400	2	.0206	.0412
405	1	.0103	.0515
415	1	.0103	.0618
420	1	.0103	.0721
425	2	.0206	.0927
435	3	.0309	.1236
440	1	.0103	.1339
445	3	.0309	.1648
450	4	.0412	.2060
455	4	.0412	.2472
460	4	.0412	.2884
465	3	.0309	.3193
470	4	.0412	.3605
475	4	.0412	.4017
480	4	.0412	.4429
485	5	.0515	.4944
490	5	.0515	.5459
495	6	.0619	.6078
500	3	.0309	.6387
505	4	.0412	.6799
410	2	.0206	.7005
515	2	.0206	.7211
520	1	.0103	.7314
530	1	.0103	.7417
535	2	.0206	.7623
540	2	.0206	.7829
545	2	.0206	.8035
550	1	.0103	.8138
555	3	.0309	.8447
560	1	.0103	.8550
580	4	.0412	.8962
585	1	.0103	.9065
590	1	.0103	.9168
595	1	.0103	.9271
605	1	.0103	.9374
640	1	.0103	.9477
655	1	.0103	.9580
715	1	.0103	.9683
730	1	.0103	.9786
735	1	.0103	.9889
885	1	.0103	.9992

APPENDIX E

Frequency Distributions for Furnace Life and Rebuild Time

Calculation of Average Furnace Life

Given Data:

Rated capacity of plant = 3,000,000 tons/yr.

Rated capacity of furnace = 400 tons/heat.

Standard outage = 7% at rated capacity.

Time to rebuild furnace = 11 days or 264 hrs.

Average heat time = 8.39 hrs./heat.

Hours available in a year = 8,760 hrs.

Calculations:

Downtime = 7% x 8,760 hrs./yr. = 613 hrs./yr.

Number of rebuilds/yr. $= \dfrac{\text{613 hrs./yr.}}{\text{264 hrs./rebuild}} =$ 2.32 rebuilds/yr.

Heats required to meet rated capacity of the plant $= \dfrac{\text{3,000,000 tons}}{\text{9 furnaces x 400 tons/furnace}} =$ 833 heats/yr.

Heats between rebuilds $= \dfrac{\text{833 heats/yr.}}{\text{2.32 rebuilds/yr.}} =$ 359 heats

Hours between rebuilds = 359 heats/rebuild x 8.39 hrs./heat = 3012 hrs.

Days between rebuilds $= \dfrac{\text{3012 hrs./rebuild}}{\text{24 hrs./day}} =$ 126 days

TABLE V

Adjustment of Lukens Steel's Frequency Distribution for Furnace Life

	Lukens Steel's Distribution		Distribution Adjusted Up One Cell Interval	
Days	**Probability**	**Probability x Days**	**Probability**	**Probability x Days**
50	.01	.50	.01	.50
60	.01	.60	.01	.60
70	.01	.70	.01	.70
80	.03	2.40	.01	.80
90	.05	4.50	.03	2.70
100	.10	10.00	.05	5.00
110	.43	47.30	.10	11.00
120	.15	18.00	.43	51.60
130	.06	7.80	.15	19.50
140	.03	4.20	.06	8.40
150	.01	1.50	.03	4.50
160	.01	1.60	.01	1.60
170	.01	1.70	.01	1.70
180	.01	1.80	.01	1.80
190	.01	1.90	.01	1.90
200	.01	2.00	.01	2.00
210	.01	2.10	.01	2.10
220	.02	4.40	.02	4.40
230	.03	6.90	.03	6.90
	Average	109.90 days	Average	127.70 days

TABLE VI

Frequency Distribution for Furnace Life

Days	Probability	Cumulative Probability
50	.01	.01
60	.01	.02
70	.01	.03
80	.01	.04
90	.03	.07
100	.05	.12
110	.10	.22
120	.43	.65
130	.15	.80
140	.06	.86
150	.03	.89
160	.01	.90
170	.01	.91
180	.01	.92
190	.01	.93
200	.01	.94
210	.01	.95
220	.02	.97
230	.03	1.00

TABLE VII

Adjustment of Lukens Steel's Frequency Distribution for Rebuild Time

	Lukens Steel's Distribution		Distribution Adjusted Down One Cell Interval	
Days	**Probability**	**Probability x Days**	**Probability**	**Probability x Days**
3	.00	.00	.01	.03
4	.01	.04	.02	.08
5	.02	.10	.04	.20
6	.04	.24	.05	.30
7	.05	.35	.08	.56
8	.08	.64	.10	.80
9	.10	.90	.13	1.17
10	.13	1.30	.15	1.50
11	.15	1.65	.11	1.21
12	.11	1.32	.06	.72
13	.06	.78	.04	.52
14	.04	.56	.04	.56
15	.04	.60	.04	.60
16	.04	.64	.02	.32
17	.02	.34	.02	.34
18	.02	.36	.02	.36
19	.02	.38	.02	.38
20	.02	.40	.01	.20
21	.01	.21	.01	.21
22	.01	.22	.01	.22
23	.01	.23	-	-
24	-	-	.01	.24
25	.01	.25	-	-
26	-	-	.01	.26
27	.01	.27	-	-
	Average	11.78 days	Average	10.78 days

TABLE VIII

Frequency Distribution for Rebuild Time

Days	Probability	Cumulative Probability
3	.01	.01
4	.02	.03
5	.04	.07
6	.05	.12
7	.08	.20
8	.10	.30
9	.13	.43
10	.15	.58
11	.11	.69
12	.06	.75
13	.04	.79
14	.04	.83
15	.04	.87
16	.02	.89
17	.02	.91
18	.02	.93
19	.02	.95
20	.01	.96
21	.01	.97
22	.01	.98
24	.01	.99
26	.01	1.00

APPENDIX F

Frequency Distribution for Ingot Sizes Produced

TABLE IX

Frequency Distribution for Ingot Sizes Produced

Type Mold	Ingot Size	Probability	Cumulative Probability
BED-OT	22 x 40	.0028	.0028
"	22 x 50	.0018	.0046
"	22 x 68	.0178	.0224
"	23 x 56	.0176	.0400
"	25 x 80	.0390	.0790
"	27 x 34	.0311	.1101
"	27 x 42	.0212	.1313
"	27 x 46	.0868	.2181
"	29 x 56	.0986	.3167
"	29 x 66	.0400	.3567
"	32 x 32	.0961	.4528
BED-BT	27 x 34	.0048	.4576
"	29 x 56	.0383	.4959
"	38 x 44	.1851	.6810
"	32 x 32	.2318	.9128
"	35 x 39	.0035	.9163
BEU-CB	32 x 32	.0837	1.0000

APPENDIX G

Frequency Distributions
for Holding Time

TABLE X

Frequency Distribution for Holding Time of Ingot Size 23 x 56

Minutes	Frequency	Probability	Cumulative Probability
40	1	.0256	.0256
45	1	.0256	.0512
50	1	.0256	.0768
55	1	.0256	.1024
60	1	.0256	.1280
65	1	.0256	.1536
70	5	.1282	.2818
75	15	.3846	.6664
80	10	.2564	.9228
85	2	.0513	.9741
90	1	.0256	.9997
	39		

TABLE XI

Frequency Distribution for Holding Time of Ingot Size 27 x 34

Minutes	Frequency	Probability	Cumulative Probability
75	3	.0968	.0968
80	13	.4194	.5162
85	4	.1290	.6452
90	4	.1290	.7742
95	1	.0323	.8065
130	1	.0323	.8388
135	2	.0645	.9033
140	1	.0323	.9356
150	1	.0323	.9679
160	1	.0323	1.0002
	31		

TABLE XII

Frequency Distribution for Holding Time of Ingot Size 27 x 42

Minutes	Frequency	Probability	Cumulative Probability
55	1	.0666	.0666
65	1	.0666	.1332
75	1	.0666	.1998
80	3	.2000	.3998
85	1	.0666	.4664
90	1	.0666	.5330
115	1	.0666	.5996
125	1	.0666	.6662
135	4	.2666	.9328
140	1	.0666	.9994
	15		

TABLE XIII

Frequency Distribution for Holding Time of Ingot Size 27 x 46

Minutes	Frequency	Probability	Cumulative Probability
60	2	.0465	.0465
65	1	.0233	.0698
70	8	.1860	.2558
75	19	.4419	.6977
80	3	.0698	.7675
85	2	.0465	.8140
125	1	.0233	.8373
130	3	.0698	.9071
135	4	.0930	1.0001
	43		

TABLE XIV

Frequency Distribution for Holding Time of Ingot Size 29 x 56

Minutes	Frequency	Probability	Cumulative Probability
40	1	.0102	.0102
45	1	.0102	.0204
60	1	.0102	.0306
70	21	.2143	.2449
75	26	.2653	.5102
80	13	.1327	.6429
85	9	.0918	.7347
90	3	.0306	.7653
95	2	.0204	.7857
110	1	.0102	.7959
150	1	.0102	.8061
155	4	.0408	.8469
160	10	.1020	.9489
165	2	.0204	.9693
170	1	.0102	.9795
185	2	.0204	.9999
	98		

TABLE XV

Frequency Distribution for Holding Time of Ingot Size 32 x 32

Minutes	Frequency	Probability	Cumulative Probability
35	1	.0100	.0100
45	1	.0100	.0200
50	2	.0200	.0400
55	5	.0500	.0900
60	5	.0500	.1400
65	1	.0100	.1500
70	1	.0100	.1600
75	6	.0600	.2200
80	13	.1300	.3500
85	21	.2100	.5600
90	14	.1400	.7000
95	1	.0100	.7100
100	5	.0500	.7600
105	1	.0100	.7700
115	2	.0200	.7900
140	1	.0100	.8000
220	1	.0100	.8100
240	2	.0200	.8300
245	3	.0300	.8600
250	3	.0300	.8900
255	2	.0200	.9100
260	2	.0200	.9300
270	1	.0100	.9400
275	1	.0100	.9500
280	1	.0100	.9600
290	1	.0100	.9700
295	2	.0200	.9900
300	1	.0100	1.0000
	100		

TABLE XVI

Frequency Distribution for Holding Time of Ingot Size 38 x 44

Minutes	Frequency	Probability	Cumulative Probability
65	1	.0196	.0196
70	14	.2745	.2941
75	17	.3333	.6274
80	7	.1373	.7647
85	5	.0980	.8627
90	2	.0392	.9019
115	1	.0196	.9215
125	2	.0392	.9607
130	1	.0196	.9803
135	1	.0196	.9999
	51		

TABLE XVII

Frequency Distribution for Holding Time of Ingot Size 22 x 68

Minutes	Frequency	Probability	Cumulative Probability
70	1	.0833	.0833
75	3	.2500	.3333
80	4	.3333	.6666
85	2	.1667	.8333
90	1	.0833	.9166
95	1	.0833	.9999
	12		

TABLE XVIII

Frequency Distribution for Holding Time of Ingot Size 25 x 80

Minutes	Frequency	Probability	Cumulative Probability
20	1	.0454	.0454
65	1	.0454	.0908
70	10	.4545	.5453
75	6	.2727	.8180
85	1	.0454	.8634
90	1	.0454	.9088
125	2	.0909	.9997
	22		

TABLE XIX

Frequency Distribution for Holding Time of Ingot Size 29 x 66

Minutes	Frequency	Probability	Cumulative Probability
30	1	.0400	.0400
45	3	.1200	.1600
70	1	.0400	.2000
75	5	.2000	.4000
80	2	.0800	.4800
85	2	.0800	.5600
90	1	.0400	.6000
140	1	.0400	.6400
155	6	.2400	.8800
160	2	.0800	.9600
165	1	.0400	1.0000
	25		

APPENDIX H

Frequency Distribution for Transit Time From Open Hearth to Stripper

TABLE XX

Frequency Distribution for Transit Time From Open Hearth to Stripper

Minutes	Frequency	Probability	Cumulative Probability
5	3	.0100	.0100
10	3	.0100	.0200
15	25	.0833	.1033
20	35	.1167	.2200
25	32	.1067	.3267
30	43	.1433	.4700
35	39	.1300	.6000
40	33	.1100	.7100
45	19	.0633	.7733
50	17	.0567	.8300
55	9	.0300	.8600
60	13	.0433	.9033
65	8	.0267	.9300
70	8	.0267	.9567
75	2	.0067	.9634
80	2	.0067	.9701
85	2	.0067	.9769
95	1	.0033	.9801
100	2	.0067	.9868
105	1	.0033	.9901
115	1	.0033	.9934
170	1	.0033	.9967
195	1	.0033	1.0000
	300		

APPENDIX I

Frequency Distributions for Stripping Time of Ingots

TABLE XXI

Frequency Distribution for Stripping Time of Ingot Sizes 23 x 56 and 27 x 46

Minutes	Frequency	Probability	Cumulative Probability
0.50	2	.0370	.0370
0.55	4	.0741	.1111
0.60	3	.0556	.1667
0.70	5	.0926	.2593
0.75	2	.0370	.2963
0.80	1	.0185	.3148
0.85	6	.1111	.4259
0.90	6	.1111	.5370
0.95	6	.1111	.6481
1.00	2	.0370	.6851
1.05	4	.0741	.7592
1.15	2	.0370	.7962
1.20	3	.0556	.8518
1.25	2	.0370	.8888
1.30	3	.0556	.9444
1.35	1	.0185	.9629
1.45	1	.0185	.9814
1.95	1	.0185	.9999
	54		

TABLE XXII

Frequency Distribution for Stripping Time of Ingot Sizes 27 x 34 and 27 x 42

Minutes	Frequency	Probability	Cumulative Probability
0.35	1	.0370	.0370
0.40	2	.0740	.1111
0.45	4	.1481	.2591
0.55	1	.0370	.2961
0.60	3	.1111	.4072
0.65	3	.1111	.5182
0.70	4	.1481	.6664
0.75	2	.0740	.7409
0.85	2	.0740	.8149
0.90	1	.0370	.8519
1.00	2	.0740	.9259
1.05	1	.0370	.9629
1.15	1	.0370	.9999
	27		

TABLE XXIII

Frequency Distribution for Stripping Time of Ingot Size 29 x 56

Minutes	Frequency	Probability	Cumulative Probability
0.40	1	.0159	.0159
0.50	2	.0317	.0476
0.55	1	.0159	.0635
0.65	1	.0159	.0794
0.70	1	.0159	.9053
0.75	3	.0476	.1429
0.80	2	.0317	.1746
0.85	8	.1270	.3016
0.95	4	.0635	.3651
1.00	2	.0317	.3968
1.05	3	.0476	.4444
1.10	1	.0159	.4603
1.15	5	.0794	.5397
1.20	3	.0476	.5873
1.25	3	.0476	.6349
1.30	4	.0635	.6984
1.35	2	.0317	.7301
1.40	1	.0159	.7460
1.45	3	.0476	.7936
1.55	3	.0476	.8412
1.60	4	.0635	.9047
1.65	1	.0159	.9206
1.75	2	.0317	.9523
1.80	2	.0317	.9846
1.85	1	.0159	.9999
	63		

TABLE XXIV

Frequency Distribution for Stripping Time of Ingot Size 32 x 32

Minutes	Frequency	Probability	Cumulative Probability
0.30	1	.0100	.0100
0.40	3	.0300	.0400
0.45	4	.0400	.0800
0.50	1	.0100	.0900
0.55	8	.0800	.1700
0.60	6	.0600	.2300
0.65	5	.0500	.2800
0.70	14	.1400	.4200
0.75	8	.0800	.5000
0.80	6	.0600	.5600
0.85	7	.0700	.6300
0.90	7	.0700	.7000
0.95	13	.1300	.8300
1.00	1	.0100	.8400
1.05	2	.0200	.8600
1.10	4	.0400	.9000
1.15	2	.0200	.9200
1.20	2	.0200	.9400
1.25	2	.0200	.9600
1.35	2	.0200	.9800
1.40	1	.0100	.9900
1.55	1	.0100	1.0000
	100		

TABLE XXV

Frequency Distribution for Stripping Time of Ingot Size 38 x 44

Minutes	Frequency	Probability	Cumulative Probability
0.70	1	.0213	.0213
0.75	1	.0213	.0426
0.80	1	.0213	.0639
0.90	2	.0426	.1065
0.95	1	.0213	.1278
1.00	1	.0213	.1491
1.05	2	.0426	.1917
1.10	2	.0426	.2343
1.20	5	.1064	.3407
1.35	3	.0638	.4045
1.40	4	.0851	.4896
1.45	1	.0213	.5109
1.55	2	.0426	.5335
1.60	1	.0213	.5748
1.65	1	.0213	.5961
1.70	1	.0213	.6174
1.75	3	.0638	.6812
2.05	3	.0638	.7450
2.20	2	.0426	.7876
2.30	1	.0213	.8089
2.35	3	.0638	.8727
2.40	1	.0213	.8940
2.50	1	.0213	.9153
3.20	1	.0213	.9366
3.35	1	.0213	.9579
3.55	2	.0426	1.0005
	47		

TABLE XXVI

Frequency Distribution for Stripping Time of Ingot Size 22 x 68

Minutes	Frequency	Probability	Cumulative Probability
0.55	1	.0909	.0909
0.70	2	.1818	.2727
0.75	1	.0909	.3636
0.80	1	.0909	.9545
0.90	1	.0909	.6363
1.10	1	.0909	.7272
1.25	1	.0909	.8181
1.40	1	.0909	.9090
1.90	1	.0909	.9090
	11		

TABLE XXVII

Frequency Distribution for Stripping Time of Ingot Sizes 25 x 80 and 29 x 66

Minutes	Frequency	Probability	Cumulative Probability
0.75	1	.0455	.0455
0.85	1	.0455	.0910
0.90	1	.0455	.1365
1.15	2	.0909	.2274
1.20	2	.0909	.3183
1.25	2	.0909	.4092
1.30	2	.0909	.5001
1.35	1	.0455	.5456
1.40	1	.0455	.5911
1.45	1	.0455	.6366
1.50	1	.0455	.6821
1.60	2	.0909	.7730
1.65	1	.0455	.8185
1.75	2	.0909	.9094
1.80	1	.0455	.9549
2.25	1	.0455	1.0004
	22		

APPENDIX J

Frequency Distribution for Reconditioning Time of Drags

TABLE XXVIII

Frequency Distribution for Reconditioning of Drags

Minutes	Probability	Cumulative Probability
70	.01	.01
80	.03	.04
90	.07	.11
100	.12	.23
110	.18	.41
120	.20	.61
130	.16	.77
140	.09	.86
150	.06	.92
160	.04	.96
170	.02	.98
180	.01	.99
190	.01	1.00

APPENDIX K

Frequency Distributions for Ingot Buggies Inoperative

TABLE XXIX

Frequency Distribution for Number of Ingot Buggies Used for Stickers per Day

Number	Frequency	Probability	Cumulative Probability
2	1	.0476	.0476
3	2	.0952	.1428
4	2	.0952	.2380
5	6	.2856	.5236
6	2	.0952	.6188
7	4	.1904	.8092
8	2	.0952	.9044
10	1	.0476	.9520
11	1	.0476	.9996
	21		

TABLE XXX

Frequency Distribution for Number of Ingot Buggies Used as Shop Buggies per Day

Number	Frequency	Probability	Cumulative Probability
2	1	.0476	.0476
3	2	.0952	.1428
4	2	.0952	.2380
5	2	.0952	.3332
6	3	.1428	.4760
7	6	.2856	.7616
8	2	.0952	.8568
9	2	.0952	.9520
10	1	.0476	.9996
	21		

TABLE XXXI

Frequency Distribution for Number of Ingot Buggies Used for Cold Steel per Day

Number	Frequency	Probability	Cumulative Probability
0	5	.2380	.2380
1	5	.2380	.4760
2	3	.1428	.6188
3	5	.2380	.8568
4	2	.0952	.9520
13	1	.0476	.9996
	21		

TABLE XXXII

Frequency Distribution for Number of Ingot Buggies Out for Repairs and Maintenance per Day

Number	Frequency	Probability	Cumulative Probability
3	1	.05	.05
5	1	.05	.10
7	11	.55	.65
8	2	.10	.75
9	3	.15	.90
10	2	.10	1.00
	20		

APPENDIX L

Calculation of Number of Ingot Buggies Required for Each Ingot Size

TABLE XXXIII

Table of Ingot Weights and Stool Type Required

Type Mold	Ingot Size	Weight (Tons)	Stool Type Required
BED-OT	22 x 40	7.42	B
"	22 x 50	9.42	B
"	22 x 68	12.71	C
"	23 x 56	11.98	B
"	25 x 80	16.51	C
"	27 x 34	7.89	B
"	27 x 42	9.89	B
"	27 x 46	12.32	B
"	29 x 56	15.47	B
"	29 x 66	16.39	C
"	32 x 32	9.49	B
BED-BT	27 x 34	7.60	B
"	29 x 56	13.43	B
"	38 x 44	19.90	B
"	32 x 32	9.43	B
"	35 x 39	16.53	B
BEU-CB	32 x 32	10.90	B

Calculation of Number of Ingot Buggies Required for a Drag of Each Ingot Size

Average Heat Size = 404.4 tons

Standard Deviation = 19.7 tons

Maximum Heat Size = 404.4 + 3 x 19.7 = 463.5 tons

Sample Calculation:

Ingot Size 22 x 40 (BED-OT)

$$\text{No. of Ingots Required} = \frac{\text{Max. Heat Size}}{\text{Ave. Ingot Weight}} = \frac{463.5 \text{ tons}}{7.42 \text{ tons}} = 62$$

$$\text{No. of Ingot Buggies Required} = \frac{\text{No. of Ingots}}{\text{Ingots/Ingot Buggy}} = \frac{62}{4} = 15\text{-}1/2^{*}$$

Total No. of Ingot Buggies Required = 16 + 1 = 17

---

* If the fraction was 1/4 (one ingot left over) the number of cars was rounded off to the smaller number. A regular size mold could be very easily placed on the trailer buggy and only three trailer ingots used. However, if the fraction was 1/2 or 3/4 the number was rounded off to the next highest number.

TABLE XXXIV

Table of Number of Ingot Buggies Required for a Drag of Each Ingot Size

Type Mold	Ingot Size	Number of Ingot Buggies Per Drag
BED-OT	22 x 40	17
"	22 x 50	13
"	22 x 68	19
"	23 x 56	11
"	25 x 80	15
"	27 x 34	16
"	27 x 42	13
"	27 x 46	11
"	29 x 56	9
"	29 x 66	15
"	32 x 32	13
BED-BT	27 x 34	10
"	29 x 56	10
"	38 x 44	7
"	32 x 32	13
"	35 x 39	8
BEU-CB	32 x 32	12

APPENDIX M

Cost of Having Ingot Buggies Available

TABLE XXXV

Summary of Repair and Maintenance Costs for Ingot Buggies

Month	Usable Tonnage Produced	R & M Costs	Cost/Ton
Sept. '58	225,349	$ 18,005	$0.0799
Oct.	219,530	10,740	0.0489
Nov.	201,453	10,869	0.0540
Dec.	219,779	23,874	0.1086
Jan. '59	220,346	15,568	0.0767
Feb.	225,958	11,080	0.0490
Mar.	255,683	7,760	0.0304
Apr.	238,609	6,063	0.0254
May	249,048	7,958	0.0320
June	217,967	14,153	0.0649
Nov.	144,245	6,190	0.0429
Dec.	238,471	8,220	0.0345
	2,656,438	$140,480	$0.0534

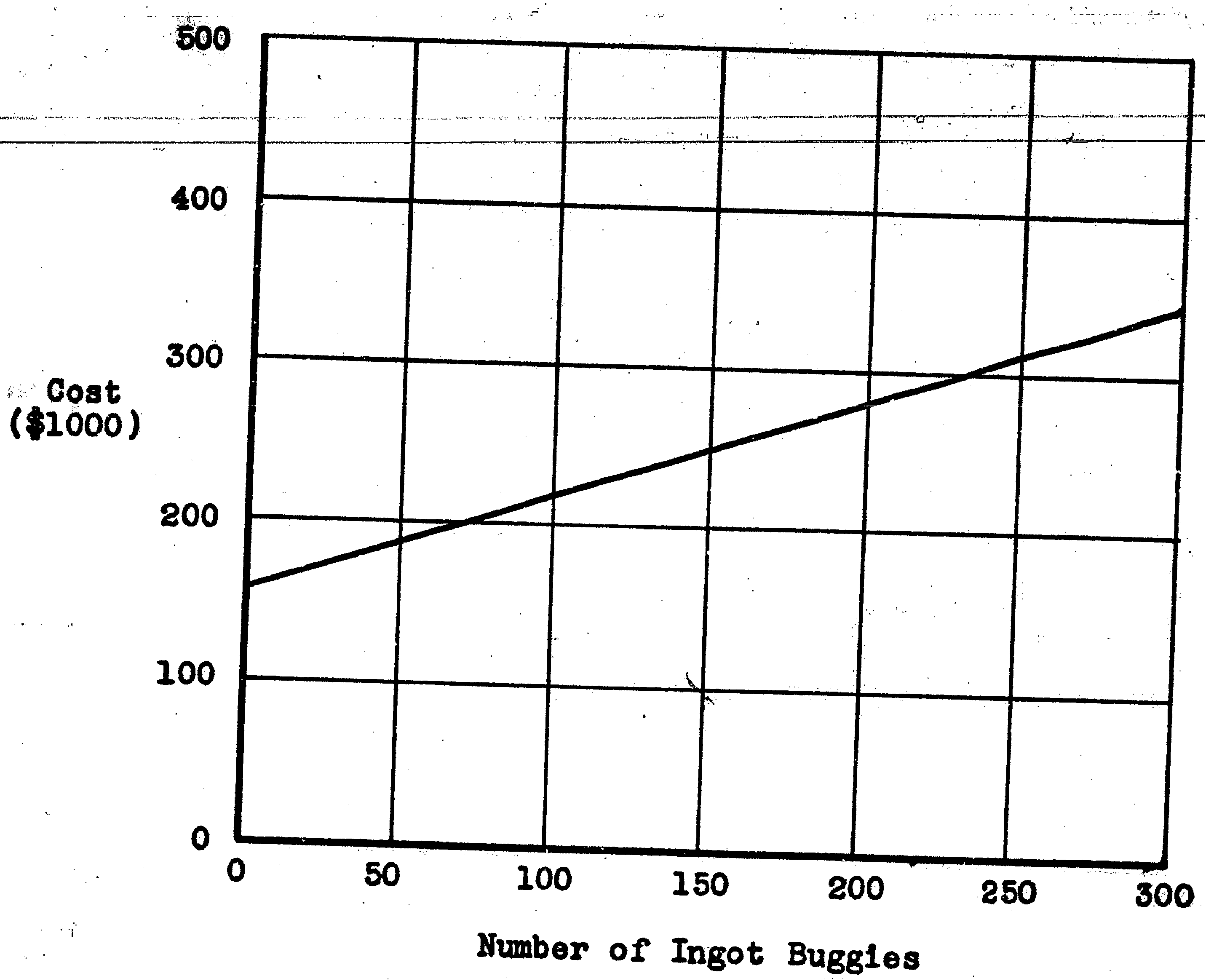


Figure 5
COST OF HAVING INGOT BUGGIES AVAILABLE
(At output of 3,000,000 ingot tons per year)

APPENDIX N

Calculation for Costs of Not Having Ingot Buggies Available

Cost of Holding a Heat in a Furnace

Cost = Cost of Operation + Loss in Profits

= \$55/hr. + \$8.25/ton

= \$55/hr. + \$398/hr.*

= \$453/hr.

* Assuming an average heat size of 404.4 tons and an average tap-to-tap time of 8.39 hours, the averages of #2 furnace, the conversion from cost per ton to cost per hour was made as follows:

$$\text{Rate of Production} = \frac{404.4 \text{ tons/heat}}{8.39 \text{ hrs./heat}} = 48.2 \text{ tons/hr.}$$

$$\text{Cost/Hr.} = 48.2 \text{ tons/hr.} \times \$8.25\text{/ton} = \$398\text{/hr.}$$

Soaking Pit Heating Cost per Hour Delay

Pit Time Required per Hour Delay = 0.482 pit hrs/delay hrs.*

Incremental Cost of Operating Soaking Pits = $6.38/pit hr.

Capacity of Soaking Pits = 3,000 tons

Assuming an average ingot weight of 12.06 tons given on the Ingot Tonnage per Month by Mold Size and Product Report,

Capacity of Soaking Pits = $\frac{3000 \text{ tons}}{12.06 \text{ tons/ingot}}$ = 250 ingots

Cost of Heating an Ingot = $\frac{\$6.38\text{/pit hr.}}{250 \text{ ingots}}$ = $0.0255/pit hr.

Cost of Heating an Ingot = $0.0255/pit hr. x 0.482 pit hrs/delay hrs.

= $0.012/hr. delay

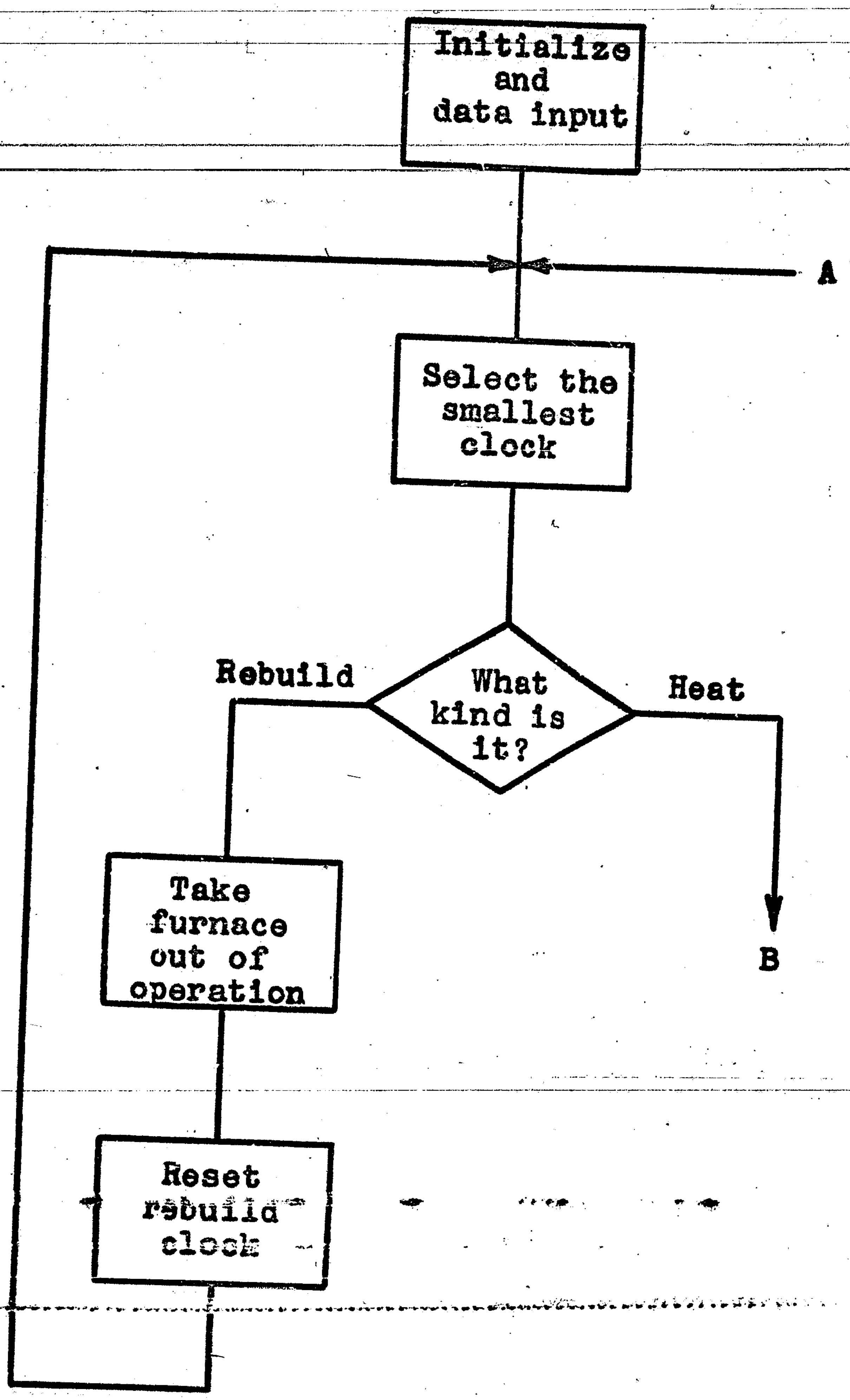
---

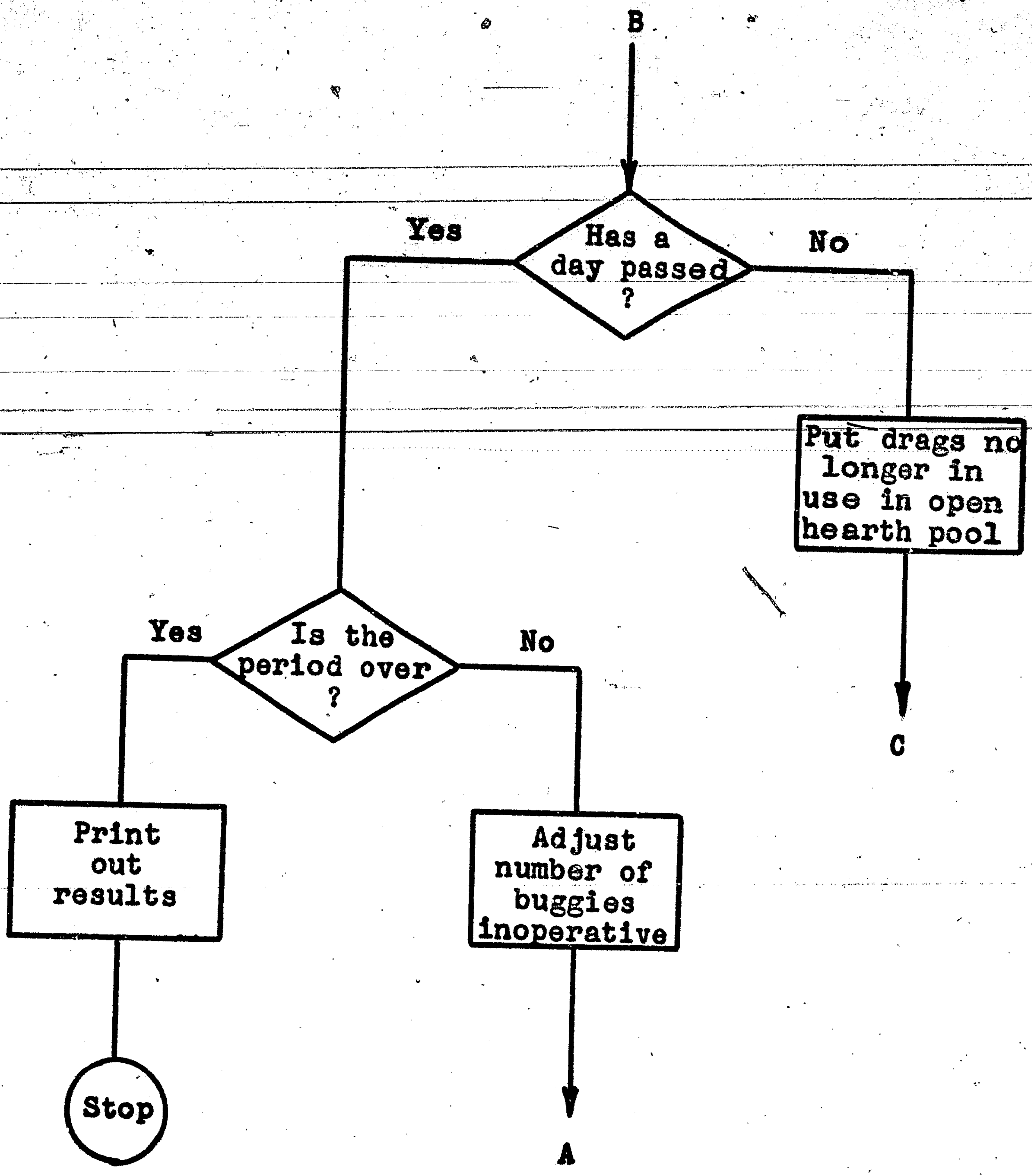
* For ingot size 32 x 32

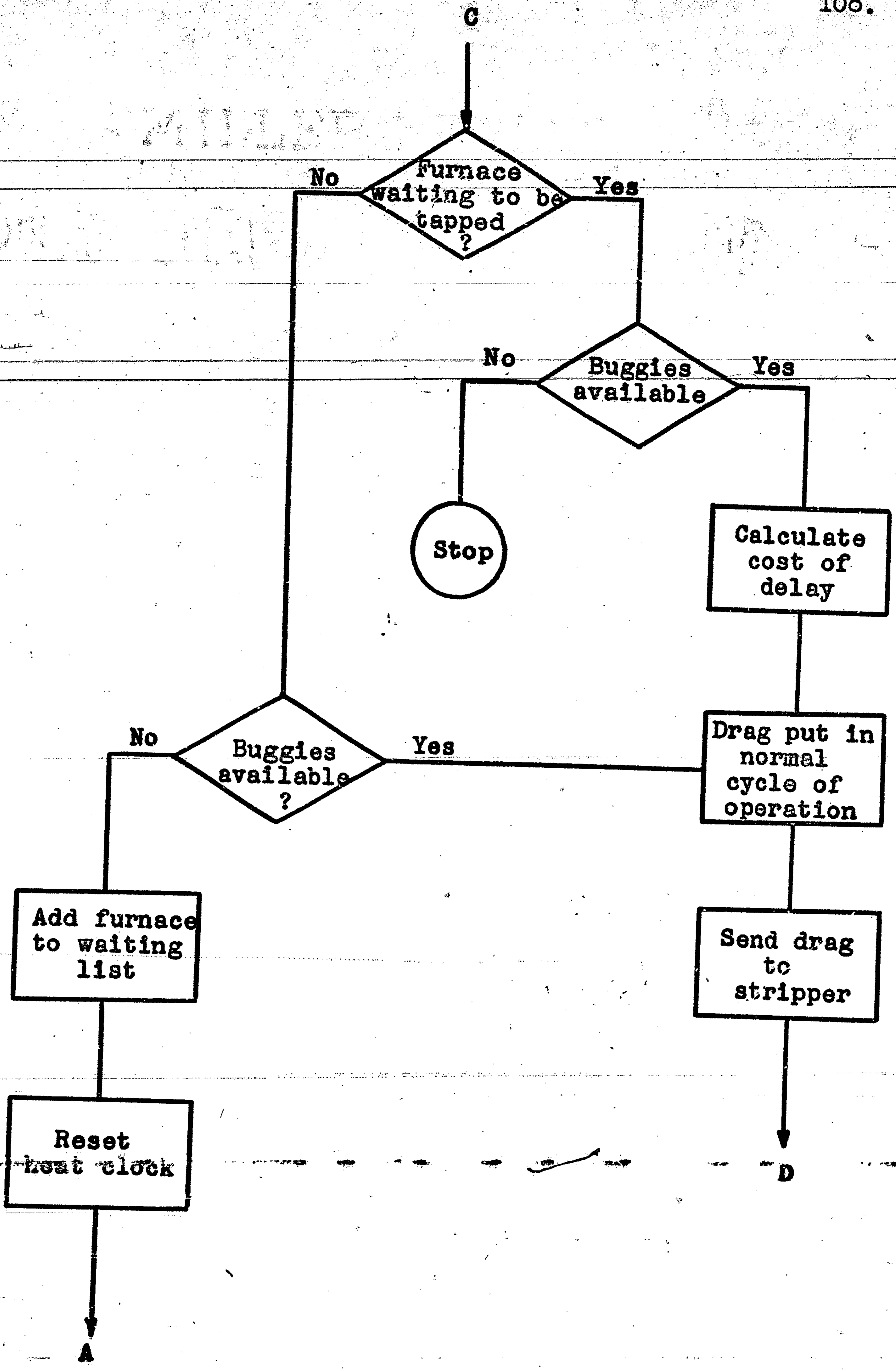
APPENDIX O

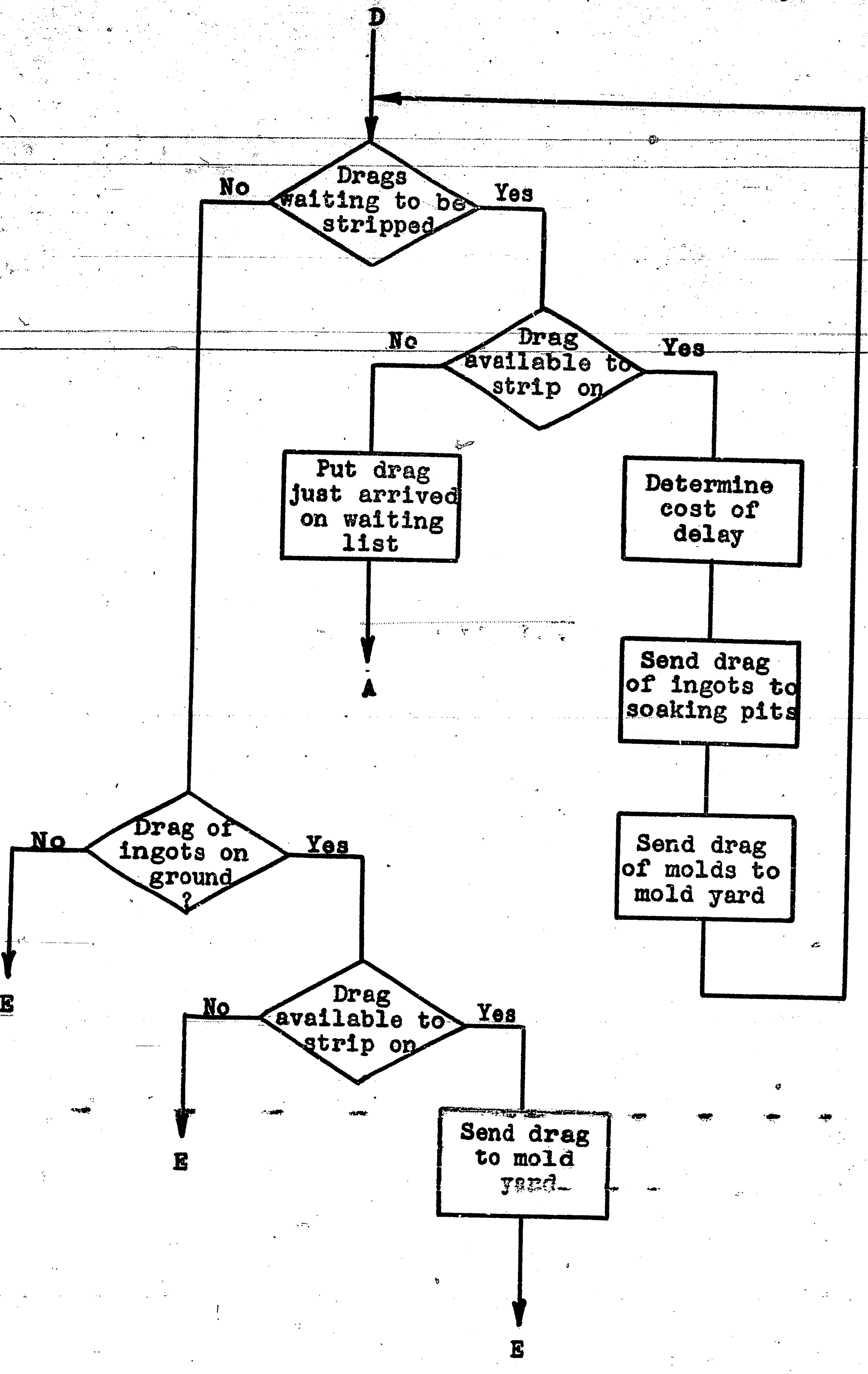
General Flow Charts for Computer Program

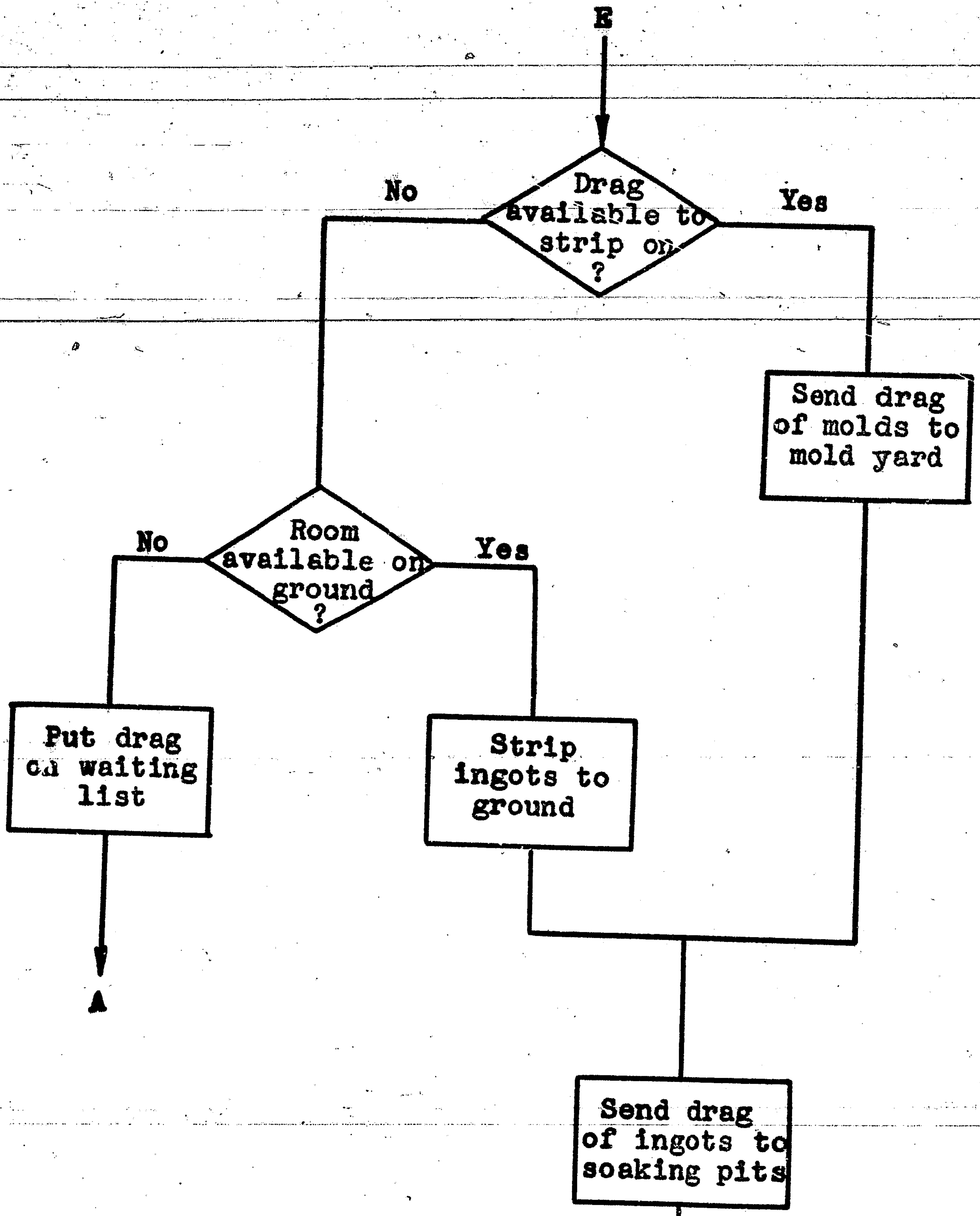
GENERAL FLOW CHARTS




B
Has a day passed ?
Yes
No
Put drags no longer in use in open hearth pool
C
Is the period over ?
Yes
No
Print out results
Stop
Adjust number of buggies inoperative
A


C
Furnace waiting to be tapped ?
No
Yes
Buggies available
No
Yes
Stop
Calculate cost of delay
Buggies available ?
No
Yes
Drag put in normal cycle of operation
Add furnace to waiting list
Send drag to stripper
Reset heat clock
D
A


D
Drags waiting to be stripped
No
Yes
Drag available to strip on
No
Yes
Put drag just arrived on waiting list
A
Determine cost of delay
Send drag of ingots to soaking pits
Send drag of molds to mold yard
Drag of ingots on ground ?
No
Yes
E
Drag available to strip on
No
Yes
E
Send drag to mold yard
E


E
Drag available to strip on ?
No
Yes
Send drag of molds to mold yard
Room available on ground ?
No
Yes
Put drag on waiting list
Strip ingots to ground
A
Send drag of ingots to soaking pits
A

APPENDIX P

ACT Program for LGP-30

ACT PROGAM

```
dim'serch'40''
dim'sampl'64''
dim'order'128''
dim'clock'20''
dim'ingwt'13''
dim'drag'13''
dim'type'13''
dim'hcost'2''
dim'lcost'2''
dim'hpool'2''
dim'spolb'30''
dim'spolc'20''
dim'hwtb'70''
dim'hwtc'20''
dim'swtb'30''
dim'swtc'20''
dim'furwt'20''
dim'outs'200''
dim'relif'100''
dim'hetim'100''
dim'trcon'100''
dim'size'50''
dim'htime'650''
index'j'k'b2'c2'f'a'i'm'b3'bl'c3'cl'j2'j3''

s100'0';'j''
s101'read'ingwt'j''
1'+'j';'j''
when'j'less'13'trn's101''
0';'j''
s102'read'drag'j''
1'+';'j''
when'j'less'13'trn's102
0';'j''
s103'read'type'j''
1'+'j';'j''
when'j'less'13'trn's103''
0';'j''
s104'read'outs'j''
1'+'j';'j''
when'j'less'200'trn's104''
0';'j''
s105'read'relif'j''
1'+'j';'j''
when'j'less'100'trn's108''
0';'j''
s110'read'hetim'j''
1'+;j';'j''
when'j'less'100'trn's110''
0';'j'
s112'read'trcon'j''
```

```
1'+'j';'j''
when'j'less'100'trn's112''
0';'j''
s114'read'size'j''
1'+'j';'j''
when'j'less'50'trn's114''
0';'j''
s115'read'htime'j''
1'+'j';'j''
when'j'less'650'trn's115''

s200'read'day''
read'bout''
read'cout''
read'hcost'0''
read'hcost'1''
read'lcost'0''
read'lcost'1''
read'tprod''
0';'j''
s120'read'clock'j''
1'+'j';'j''
when'j'less'20'trn's120''
read'fcost''
read'lcst''
read'perid''
read'shadj''
read'hpool'0''
read'hpool'1''
read'j2''
0';'j''
s121'read'spolb'j''
1'+'j';'j''
when'j'less'j2'trn's121''
read'j3''
0';'j''
s122'read'spolc'j''
1'+'j';'j''
when'j'less'j3'trn's122''
0';'hwtb'0''
0';'hwtc'0''
0';'swtb'0''
0';'swtc'0''
0';'b1''
0';'c1''
0';'b2''
0';'c2''
0';'b3''
0';'c3''
0';'f''
s1'sub'serch'clock'k''
stop''
when'k'grt'9'trn's2''
when'k'equal'9'trn's113''
```

```
clock'k';'r''
stop''
s42'when'r'grt'day'trn's3''
s7'when'r'grt'hwtb'b2'trn's5''
s8'when'r'grt'hwtc'c2'trn's6''
when'furwt'f'grt'0'trn's9''
r'+'9999';'clock'9''
sub'sampl'hetim'0'h''
h'+'tprod';'tprod''
sub'sampl'size'0'a''
stop''
type'a';'i''
,','h'x'1000'.'/'ingwt'a'.'+'9';'nngot''
nngot'/'10';'nngot''
drag'a';'y''
when'hpool'i'less'y'trn's10''
hpool'i'-'y';'hpool'i''
stop''
use's12''
s2'clock'k';'r''
k'-'10';'m''
sub'sampl'relif'0're''
,'re'x'1440'.'+'clock'm';'f1''
f1'+'r';'clock'm''
shadj'+'clock'm';'clock'm''
sub'sampl'relif'1'li''
,','li'x'1440'.'+'f1'.'+'clock'k';'clock'k''
use's1''
s113'clock'9'+'5';'clock'9''
clock'9';'r''
use's42''
s3'when'r'grt'perid'trn's4''
day'+'1440';'day''
bout'+'hpool'0';'hpool'0''
cout'+'hpool'1';'hpool'1''
sub'sampl'outs'0'u''
sub'sampl'outs'1'u1''
u'+'u1';'u''
sub'sampl'outs'2'u1''
u'+'u1';'u''
sub'sampl'outs'3'u1''
u'+'u1';'u''
stop''
u'x'835';'bout''
bout'/'1000';'u4''
bout'-','u4'x'1000'.';'u5''
,','u4'x'1000'.'+','u5'x'2'.'.';'u6''
u6'/'1000';'bout''
hpool'0'-'bout';'hpcol'0''
u'-'bout';'cout''
hpool'1'-'cout';'hpool'1''
use's1''
s4'cr''
```

```
0'print'tprod''
cr''
2'print'hcost'0''
cr''
2'print'hcost'1''
cr''
2'print'lcost'0''
cr''
2'print'lcost'1''
cr'cr''
0';'k''
s64'0'print'clock'k''
cr''
1'+'k';'k''
when'k'less'20'trn's64''
cr'cr''
0';'j''
s65'0'print'spolb'j''
1'+'j';'j''
0'print'spolb'j''
cr''
1'+'j';'j''
when'j'lesm'30'trn's65''
cr'cr''
0';'j''
s66'0'print'spolc'j''
1'+'j';'j''
0'print'spolc'j''
cr''
1'+'j';'j''
when'j'less'20'trn's66''
cr''
use's200''
s5'0';'hwtb'b2''
1'+'b2';'b2''
hwtb'b2'+'hpool'0';'hpool'0''
stop''
0';'hwtb'b2''
1'+'b2';'b2''
use's7''
s6'0';'hwtc'c2''
1'+'c2';'c2''
hwtc'c2'+'hpool'1';'hpool'1''
stop''
0';'hwtc'c2''
1'+'c2';'c2''
use's8''
s9'1'+'f';'f''
1'unpak'furwt'f';'p1''
stop''
2'unpak'furwt'f';'a''
stop''
p1'/'100';'p2''
```

```
p2'x'100';'p3''
pl'-'p3';'k''
,'pl'-'k'.'/'100';'nngot''
drag'a';'y''
type'a';'i''
when'y'grt'hpool'i'trn'sll''
hpool'i'-'y';'hpool'i''
f'-'l';'f''
,','r'-'furwt'f'.'x'fcost'.'+'hcost'i';'hcost'i''
,'r'-'furwt'f'.'+'r';'clock'k''
0';'furwt'f''
l'+'f';'f''
0';'furwt'f''
l'+'f';'f''
use'sl4''
sll'cr''
0'print'77777''
use'sll''
sl2'sub'sampl'hetim'l'rl''
rl'+'r';'r''
r';'clock'k''
sl4'sub'sampl'htime'a'rl''
rl'+'r';'r''
sub'sampl'trcon'0'rl''
rl'+'r';'r''
use's30''
sl0'nngot'x'100';'pl''
pl'+'k';'pl''
pl'pak'a';'p''
sub'order'furwt'f'r'p''
0';'f''
sub'sampl'hetim'l'rl''
rl'+'r';'clock'k''
r';'clock'9''
use'sl''
s30'when'swtb'b3'equal'0'trn's31''
when'swtc'c3'equal'0'trn's32''
when'swtc'c3'less'swtb'b3'trn's33''
when'spolb'bl'equal'0'trn's34''
ret's152''
use's40''
use's30''
s31'when'swtc'c3'equal'0'trn's45''
when'spolc'cl'equal'0'trn's45''
ret's152''
use's41''
use's31''
s32'when'spolb'bl'equal'0'trn's45''
ret's152''
use's40''
use's35''
s35'when'swtb'b3'equal'0'trn's45''
use's32''
s45'2'unpak'grctr';'a5''
```

```
stop''
when'a5'equal'20'trn's46''
i';'q''
a';'a4''
nngot';'nnn''
2'unpak'grctr';'a''
1'unpak'grctr';'nngot''
type'a';'i''
when'i'equal'0'trn's81''
when'spolc'cl'equal'0'trn's61''
0';'spolc'cl''
1'+'cl';'cl''
spolc'cl';'sno''
0';'spolc'cl''
1'+'cl';'cl''
ret's150''
use's51''
s61'q';'i''
a4';'a''
nnn';'nngot''
0'pak'20';'grctr''
use's46''
s81'when'spolb'bl'equal'0'trn's61''
0';'spolb'bl''
1'+'bl';'bl''
spolb'bl';'sno''
0';'spolb'bl''
1'+'bl';'bl''
ret's150''
use's51''
use's61''
s46'when'i'equal'0'trn's84''
when'spolc'cl'equal'0'trn's86''
0';'spolc'cl''
1'+'cl';'cl''
spolc'cl';'sno''
0';'spolc'cl''
1'+'cl';'cl''
ret's150''
use's51''
ret's151''
use's54''
use's1''
s84'when'spolb'bl'equal'0'trn's86''
0';'spolb'bl''
1'+'bl';'bl''
spolb'bl';'sno''
0';'spolb'bl''
1'+'bl';'bl''
ret's150''
use's51''
ret's151''
use's54''
use's1''
```

```
s86'2'unpak'grctr';'a5''
when'a5'equal'20'trn's58''
when'i'equal'0'trn's88''
sub'order'swtc'c3'r'y''
0';'c3''
use'sl''
s88'sub'order'swtb'b3'r'y''
0';'b3''
use'sl''
s58'nngot'pak'a';'grctr''
ret's151''
use's54''
use'sl''
s54'137';'r6''
,',' nngot'x'r6'.'/'100'.'+'r';'r6''
11'+'r6';'r6''
stop''
,',' nngot'x'152'.'/'100'.'+'r6';'r6''
stop''
when'i'equal'0'trn's92''
sub'order'spolc'cl'r6'y''
0';'cl''
s151'use'exit''
s92'sub'order'spolb'bl'r6'y''
0';'bl''
use's151''
s33'when'spolc'cl'equal'0'trn's36''
ret's152''
use's41''
use's30''
s36'when'spolb'bl'equal'0'trn's45''
ret's152''
use's40''
use's30''
s34'when'spolc'cl'equal'0'trn's45''
ret's152''
use's41''
use's30''
s40'r';'r8''
a';'a4''
y';'y3''
nngot';'w''
i';'q''
1'+'b3';'b3''
swtb'b3';'p''
stop''
1'unpak'p';'nngot''
2'unpak'p';'a''
type'a';'i''
drag'a';'y''
b3'-'1';'b3''
spolb'bl'-'swtb'b3';'ccc''
ccc'x'nngot';'ccc''
ccc'x'lcst';'ccc''
```

```
ccc'+'lcost'0';'lcost'0''
0';'swtb'b3''
1'+'b3';'b3''
0';'swtb'b3''
1'+'b3';'b3''
spolb'b1';'r''
0';'spolb'b1''
1'+'b1';'b1''
spolb'b1';'sno''
0';'spolb'b1''
1'+'b1';'b1''
ret's150''
use's51''
ret's151''
use's54''
s60'w';'nngot''
q';'i''
y3';'y''
a4';'a''
r8';'r''
s152'use'exit''
s41'r';'r8''
a';'a4''
y';'y3''
nngot';'w''
i';'q''
1'+'c3';'c3''
swtc'c3';'p''
stop''
1'unpak'p';'nngot''
2'unpak'p';'a''
type'a';'i''
drag'a';'y''
c3'-'1';'c3''
spolc'c1'-'swtc'c3';'ccc''
ccc'x'nngot';'ccc''
ccc'x'lcst';'ccc''
ccc'+'lcost'1';'lcost'1''
0';'swtc'c3''
1'+'c3';'c3''
0';'swtc'c3''
1'+'c3';'c3''
spolc'c1';'r''
0';'spolc'c1''
1'+'c1';'c1''
spolc'c1';'sno''
0';'spolc'c1''
1'+'c1';'c1''
ret's150''
use's51''
ret's151''
use's54''
w';'nngot''
q';'i''
```

```
y3';'y''
a4';'a''
r8';'r''
use's152''
s51'137';'al''
,','al'x'nngot'.'/'100'.'+'r';'r2''
stop''
sub'sampl'trcon'0'rl''
rl'+'r2';'r2''
sub'sampl'trcon'l'rl''
stop''
rl'+'r2';'r2''
when'i'equal'0'trn's77''
sub'order'hwtc'c2'r2'sno''
0';'c2''
s150'use'exit''
s77'sub'order'hwtb'b2'r2'sno''
0';'b2''
use's150'''
```

APPENDIX Q

Definition of Symbols

Used in ACT

Definitions of Symbols Used in ACT

0 - type B ingot buggy

1 - type C ingot buggy

a - ingot size

bout - the number of type B cars inoperative

clock - the clocks for furnace heat time and rebuild time

cout - the number of type C ingot buggies inoperative

day - clock to keep track of days

drag - the number of ingot buggies in a drag for ingot size poured

f - counter for furnace waiting list

fcost - the cost per minute of furnace delay

furwt - list for number of furnaces waiting to be tapped

grctr - counter to determine if any ingots have been stripped

h - the size of the heat in tons

hetim - frequency distributions for heat size and tap-to-tap time

hpool - open hearth pool

htime - frequency distributions for holding time of each ingot size

hwtb - the open hearth waiting list for type B buggies

hwtc - the open hearth waiting list for type C buggies

i - the type of ingot buggy required

ingwt - the weight of the ingot

k - the smallest clock number

Definitions of Symbols (Cont'd)

li - the length of time between rebuilds

lcost - the total cost of stripping delay

lcst - the cost per minute of stripping delay

m - the rebuild clock number

nngt - the number of ingots poured

order - subroutine used to add to heats

outs - frequency distributions for ingot buggies inoperative

p - storage spaces used for manipulation of data

perid - time at end of the period

r - time of smallest clock

re - time required to rebuild the furnace

relif - frequency distributions for rebuild and furnace life

sampl - subroutine used to pick a number at random from a frequency distribution

serch - subroutine used to select the smallest clock

shadj - shutdown adjustment factor

size - the ingot size poured

sno - the number of buggies sent from the stripper to the mold yard

spolb - the stripper pool for type B drags

spolc - the stripper pool for type C drags

swtb - list for type B drags waiting to be stripped

swtc - list for type C drags waiting to be stripped

tprod - the total production in ingot tons for the period

trcon - frequency distributions for transit time and reconditioning time

type - the type buggy required for the ingot size poured

y - the number of cars in the drag

APPENDIX R

Data for ACT Program

DATA FOR ACT PROGRAM

```
1198'789'989'1232'1547'949'1343'1990'943'1090'1271'1651'1639'
11'16'13'11'9'13'10'7'13'12'19'15'15'
0'0'0'0'0'0'0'0'0'0'1'1'1'
3'3'3'5'5'7'7'7'7'7'
7'7'7'7'7'7'7'7'7'7'
7'7'7'7'7'7'7'7'7'7'
7'7'7'8'8'8'8'8'9'9'
9'9'9'9'9'10'10'10'10'10'
2'2'2'3'3'3'3'4'4'4'
4'4'5'5'5'5'5'5'5'5'
5'5'5'5'5'5'6'6'6'6'
6'7'7'7'7'7'7'7'7'7'
7'8'8'8'8'10'10'10'11'11'
2'2'2'3'3'3'3'4'4'4'
4'4'5'5'5'5'5'6'6'6'
6'6'6'6'7'7'7'7'7'7'
7'7'7'7'7'7'7'7'8'8'
8'8'8'9'9'9'9'9'10'10'
0'0'0'0'0'0'0'0'0'0'
0'0'1'1'1'1'1'1'1'1'
1'1'1'1'2'2'2'2'2'2'
2'2'3'3'3'3'3'3'3'3'
3'3'3'4'4'4'4'4'13'13'
3'4'5'5'6'6'7'7'7'7'
8'8'8'8'8'9'9'9'9'9'
9'9'10'10'10'10'10'10'10'11'
11'11'11'11'11'12'12'12'13'13'
14'14'15'15'16'17'18'19'21'24'
50'70'90'90'100'100'110'110'110'110'
110'120'120'120'120'120'120'120'120'120'
120'120'120'120'120'120'120'120'120'120'
120'120'120'130'130'130'130'130'130'130'
140'140'140'150'150'170'190'210'220'230'
288'364'370'382'382'386'390'390'390'392'
394'398'398'398'400'400'400'402'402'404'
404'404'406'406'408'408'408'410'410'410'
410'410'412'412'414'414'414'416'416'416'
418'418'420'420'424'424'426'428'434'442'
390'400'405'420'425'435'440'445'450'450'
450'455'455'460'460'465'470'470'475'475'
480'480'485'485'485'490'490'490'495'495'
495'500'505'505'510'515'520'535'540'545'
550'555'560'580'580'585'595'640'715'735'
5'15'15'15'15'20'20'20'20'20'
20'25'25'25'25'25'25'30'30'30'
30'30'30'30'35'35'35'35'35'35'
40'40'40'40'40'40'45'45'45'50'
50'50'55'60'60'65'65'70'80'100'
70'80'90'90'90'90'100'100'100'100'
100'100'110'110'110'110'110'110'110'110'
110'120'120'120'120'120'120'120'120'120'
```

120'130'130'130'130'130'130'130'130'140'
140'140'140'150'150'150'160'160'170'180'
0'1'1'2'3'3'3'3'4'4'
4'4'4'5'5'5'5'5'6'6'
7'7'7'7'7'7'7'7'7'8'
8'8'8'8'8'8'8'8'8'8'
8'9'9'9'9'10'11'11'12'12'
40'40'45'50'55'60'60'65'70'70'
70'70'70'70'75'75'75'75'75'75'
75'75'75'75'75'75'75'75'75'75'
75'75'75'75'80'80'80'80'80'80'
80'80'80'80'80'80'85'85'85'90'
75'75'75'75'75'80'80'80'80'80'
80'80'80'80'80'80'80'80'80'80'
80'80'80'80'80'80'80'85'85'85'
85'85'85'90'90'90'90'90'90'95'
95'130'135'135'135'140'140'150'150'160'
55'55'55'55'65'65'65'75'75'75'
80'80'80'80'80'80'80'80'80'80'
85'85'85'85'90'90'90'115'115'115'
125'125'125'135'135'135'135'135'135'135'
135'135'135'135'135'135'135'140'140'140'
60'60'60'65'70'70'70'70'70'70'
70'70'70'75'75'75'75'75'75'75'
75'75'75'75'75'75'75'75'75'75'
75'75'75'75'75'80'80'80'80'85'
85'125'130'130'130'130'135'135'135'135'
40'60'70'70'70'70'70'70'70'70'
70'70'70'75'75'75'75'75'75'75'
75'75'75'75'75'75'80'80'80'80'
80'80'85'85'85'85'85'90'90'95'
150'155'155'160'160'160'160'160'165'185'
35'50'55'55'55'60'60'65'75'75'
75'80'80'80'80'80'80'80'85'85'
85'85'85'85'85'85'85'85'90'90'
90'90'90'90'90'95'100'100'105'115'
220'240'245'250'250'255'260'275'290'295'
40'60'70'70'70'70'70'70'70'70'
70'70'70'75'75'75'75'75'75'75'
75'75'75'75'75'75'80'80'80'80'
80'80'85'85'85'85'85'90'90'95'
150'155'155'160'160'160'160'160'165'185'
65'70'70'70'70'70'70'70'70'70'
70'70'70'70'70'75'75'75'75'75'
75'75'75'75'75'75'75'75'75'75'
75'75'80'80'80'80'80'80'85'85'
85'85'85'90'90'115'125'125'130'135'
35'50'55'55'55'60'60'65'75'75'
75'80'80'80'80'80'80'80'85'85'
85'85'85'85'85'85'85'85'90'90'
90'90'90'90'90'95'100'100'105'115'
220'240'245'250'250'255'260'275'290'295'
35'50'55'55'55'60'60'65'75'75'
75'80'80'80'80'80'80'80'85'85'

```
85'85'85'85'85'85'85'85'90'90'
90'90'90'90'90'95'100'100'105'115'
220'240'245'250'250'255'260'275'290'295'
70'70'70'70'75'75'75'75'75'75'
75'75'75'75'75'75'75'80'80'80'
80'80'80'80'80'80'80'80'80'80'
80'80'80'85'85'85'85'85'85'85'
85'85'90'90'90'90'95'95'95'95'
20'20'20'65'65'70'70'70'70'70'
70'70'70'70'70'70'70'70'70'70'
70'70'70'70'70'70'70'70'75'75'
75'75'75'75'75'75'75'75'75'75'
75'85'85'90'90'90'125'125'125'125'
30'30'45'45'45'45'45'45'70'70'
75'75'75'75'75'75'75'75'75'75'
80'80'80'80'85'85'85'85'90'90'
140'140'155'155'155'155'155'155'155'155'
155'155'155'155'160'160'160'160'165'165'
0'0'0'0'0'0'0'0'
86'250'296'156'319'486'423'552'202'
100000'
96163'59621'258905'56487'7654'69714'224896'106368'288779'-0000001'
755'1'44640'
0'
200'
35'
8'1'10'2'11'3'13'4'16'
2'5'15'
```

BIBLIOGRAPHY

Calhoun, Reed S. "Applications of Monte Carlo Simulation in a Steel Company," a paper presented at the American Society for Quality Control in New York City, February 26-27, 1960.

Churchman, C. West, Ackoff, Russell L., and Arnoff, E. Leonard. Introduction to Operations Research. New York: John Wiley & Sons, Inc., 1957.

Goode, Harry H. and Machol, Robert E. System Engineering. New York: McGraw-Hill Book Company, Inc., 1957.

Mode, Elmer B. Elements of Statistics. Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1951.

Moroney, M. J. Facts from Figures. London: Penquin Books Ltd., 1958.

Sasieni, Maurice, Yaspan, Arthur, and Friedman, Lawrence. Operations Research. New York: John Wiley & Sons, Inc., 1959.

BIOGRAPHY OF CANDIDATE

NAME:	Marlyn L. Rabenold
DATE OF BIRTH:	February 3, 1938
PLACE OF BIRTH:	Route 1, Alburtis, Pennsylvania
PARENTS:	Luther L. Rabenold Marian I. C. Rabenold

EDUCATIONAL BACKGROUND

Institutions Attended

Pennsylvania State University
University Park, Pennsylvania
Lehigh University
Bethlehem, Pennsylvania

Degrees Awarded

Bachelor of Science, Industrial Engineering
Pennsylvania State University
June 6, 1959

Honors Awarded

Honor Graduate, Pennsylvania State University
Tau Beta Pi
Sigma Tau
Alpha Pi Mu
Phi Kappa Phi
Phi Eta Sigma

PROFESSIONAL EXPERIENCE

The Procter & Gamble Company
Cincinnati, Ohio
June, 1959 to August, 1959

Pennsylvania Power & Light Company
Allentown, Pennsylvania
June, 1957 to August, 1957

PROFESSIONAL SOCIETIES

Pennsylvania Society of Professional Engineers