Iron and Steelmaking Facility Planning Simulation Model

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INTRODUCTION

Simulation models of iron and steelmaking facilities have been successfully developed to test the productive capabilities of numerous plants. The models simulate actual operations of the facilities reflecting internal cycle times and delays. Input data establishes the frequency, duration, and variability of essential shop events. Interaction of the facilities is also recognized in the design of the models. External delays, where facilities interface, develop in the models as they operate.

Numerous objectives exist in the design of simulation models for this type of facility complex. The scope of the model varies from the study of new facilities in existing plants to entirely new plants. Productivity of individual facilities and of the overall plant is a universal objective. This, of course, entails the determination of resource utilization and bottlenecks. Specific models frequently require an examination of alternative design proposals where facility capacities, quantity, and location vary. Other models require the study of alternative operating practices in a specific facility which can drastically alter overall plant performance.

A discussion of all the potential variation in an iron and steelmaking complex, or even of all the facilities in one plant, would result in a topic too expansive to cover in the framework of this presentation. Therefore, representative, critical facilities and events have been selected for discussion.

The majority of current world steel production comes from the basic oxygen furnace (BOF) process. The vast majority of new steelmaking plants are BOF shops, therefore, the BOF shop is our natural example. In the first part of the presentation, individual facilities including blast furnaces, mixers, scrap yard, basic oxygen furnaces, teeming platforms, and continuous casters are described briefly to provide a basis for the discussion of facility interactions covered in the second part. The final section is a discussion of data and premise philosophy, the model itself, and the conclusion of the presentation.

FACILITIES

IRON PRODUCTION

The primary ingredient of steel is iron. The primary iron production facility is the blast furnace. At the blast furnace, iron oxides, coke used as fuel and as a chemical reaction agent, together with limestone and dolomite (fluxes that facilitate chemical reactions) are charged at the top of the furnace. Air, and frequently fuel, is blown into the furnace at the bottom. Heat increases as the burden slowly descends in the furnace, resulting in oxidation and reduction reactions which produce iron of over 90 percent purity. The iron is then cast into cigar-shaped, refractory-lined, small-mouthed "torpedo" ladles which are mounted on rails. Railroad engines transport the "hot metal" in the ladles to the steelmaking complex.

MIXERS

When a set of torpedoes, referred to as a "drag", arrives at the steelmaking complex, it is hauled up a large ramp and spotted on a track at the mixers. The torpedoes rotate on a horizontal axis for pouring into a mixer. The mixer, a large, refractory-lined tank, serves as a sink for hot metal while smoothing the gap between blast furnace production and steelmaking consumption of hot metal. Additionally, the mixer is minimizing the time that the expensive torpedo ladles must wait to pour, and reducing the overall complement of ladles required to prevent excessive delays at the blast furnaces and at the steelmaking complex.

Once in the mixer, the hot metal remains there until one of the basic oxygen furnaces begins a new production cycle called a "heat". When the start of a heat approaches, the amount of hot metal required to produce the heat is poured

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from the mixer into a charging ladle.

SCRAP YARD

The second major ingredient of steel is steel scrap. A scrap yard in an aisle parallel to the basic oxygen furnaces prepares the scrap for charging. Overhead electromagnetic cranes load the scrap into boxes. When full, the boxes move to the basic oxygen furnace charging aisle on transfer cars mounted on rails.

BASIC OXYGEN FURNACE

The basic oxygen furnace is a large, pear-shaped vessel in which molten iron, scrap steel, and fluxes are converted into steel.

Operation of the BOF first involves rotation of the open-mouthed vessel on a horizontal axis toward the charging aisle. An overhead crane transports the scrap box to the vessel and charges the scrap into the furnace. A second overhead crane transfers the ladle of molten iron to the vessel and charges it. At this point, the vessel is returned to an upright position under a large hood. A lance is lowered through a hole in the center of the hood, and 90 to 99 percent pure oxygen blows into the vessel through the lance, facilitating rapid metallurgical reactions which further eliminate impurities. In many plants, the oxygen supply capacity is limited, and only one vessel can be blown at a time. During the blow, a third material, flux, is charged into the furnace. The lime, fluorspar, and scale fluxes contained in bins over the furnace are charged in chutes through the hood.

Completing the blow, the vessel is again tilted toward the charging aisle and a sample is taken for analysis. If the test is failed, a reblow is performed and a final test taken. The heat is then ready to be tapped into a pouring ladle, which will be transferred to the pitside.

TEEMING

At the pitside the ladle takes one of two paths. In the first, an overhead crane hoists the ladle to a pouring platform where the liquid steel is poured or teemed into ingot molds. The molds are set on stools which, in turn, are set on buggies mounted on rails. When the entire heat is teemed, railroad engines move the ingots to an appropriate area for further processing.

CONTINUOUS CASTING

The alternative path is to the continuous caster. The ladle is raised by an overhead crane to the caster level which rises 25 to 70 feet above ground level. Here, the liquid steel slowly pours into a tundish ladle which releases the steel into one or more open-end molds, producing a long strand or strands of steel. The strands solidify as they pass through water-cooled molds and are then cut into slabs, blooms, or billets during the vertical descent or at ground level. The product is removed from the steel-making facility by table rolls that lead to rail transfer cars.

FACILITY INTERACTION

INTRODUCTION

The basic oxygen furnace is the focal point of the entire iron and steelmaking complex. All major facilities have a direct or buffered interaction with the basic oxygen furnace and interact with each other through the BOF. Delays in the preparation of hot metal or scrap slow down BOF production which, in turn, delays the facilities that follow. Delays in the facilities subsequent to the BOF also delay the BOF which, in turn, forces the hot metal and scrap preparation facilities to slow down their operations.

BLAST FURNACE - MIXER - BOF

We have already described the basic interaction of the blast furnace, mixer, and BOF, but the full level of complexity remains to be examined. Almost every steelmaking complex contains more than one blast furnace. Each blast furnace is subject to both production cycle delays and variations, and to maintenance delays incurred at the end of a cast. Production cycles alter when torpedo and engine availability problems arise.

Blast furnace production requires close monitoring. When traffic problems occur, or mixers fill, blast furnace production must decrease. This is accomplished by reducing the rate at which air blows into the furnace. In the model, it is also recognized by extending the production cycle. In some cases, torpedo ladles must be emptied by casting their contents in a special blast furnace area.

When BOF consumption exceeds blast furnace production of hot metal, delays external to the BOF production cycle develop as a result of the shortage.

Mixers and basic oxygen furnaces incur refractory reline outages which can require one to two week periods. Basic oxygen furnaces experience production cycle delays and variations. In addition, a few minutes are required to dump slag out of the furnace after each heat. Maintenance delays ranging from minutes to hours occur periodically at the end of a heat.

SCRAP YARD - BOF

BOF consumption of scrap periodically outstrips the yard's capacity to load scrap boxes, which results in external BOF cycle delays. This situation is most commonly encountered when a crane in the scrap yard incurs a planned or unplanned maintenance outage. On the other hand, there are a limited number of scrap boxes, and the scrap cranes are idled when all the boxes are full.

CHARGING AISLE - BOF

Cranes are required in all areas of steel production and greatly increase the complexity of the model. Those in the charging aisle of the BOF operation are subject to maintenance outages. One crane frequently performs the duties of two during outage periods, however, this normally results in delays in both crane service areas.

Having come to the completion of the input side of the BOF, we now turn to the pitside, where teeming and casting operations are performed.

BOF - TEEMING - CASTING

The temperature of the molten steel is a critical factor in pitside operations. The more steel cools, the more difficult the operations become. Casting becomes impossible after steel remains in the ladle for several hours. For this reason, a heat does not begin the production cycle unless a continuous caster or ingot teeming platform is likely to be available to process it at its completion.

A platform requires an overhead crane for service. Again, the cranes are subject to repair outages. The platforms incur minor or major delays after each heat. At best, ingot buggies must be removed from the platform after a heat is completed and replacement buggies must be spotted. At worst, the platform area requires extensive clean-up periods to remove steel that has splashed out of the molds and onto the ground.

Casters are also serviced by cranes subject to outages. Most large, high tonnage casters do not attain a casting utilization in excess of 55 percent. Caster outages generally include weekly and annually planned maintenance. Molds must be changed periodically as product dimensions change. Strands fail due to mechanical, electrical, and miscellaneous problems. In addition, strands can "break out". This occurs when molten steel encased in a thin crust of cooled surface steel breaks out of the skin. This results in extensive clean-up periods. In addition, casting rates are subject to variation.

A further complication in caster production is encountered. Synchronization of basic oxygen vessel and caster operations is critical. Within a set of constraints, the objective of a caster operation is to cast heats sequentially in what is termed a "string" or "continuous-continuous" casting. At the end of each string, maintenance delays are automatically encountered. When the ladle currently filling the tundish empties, it must be removed and a replacement ladle positioned to pour before the tundish has emptied or the string is broken. In addition, the ladle must be emptied within the time limit or the liquid steel will be too cold to cast, and again, the string breaks. In addition, problems with ladles, temperature, and chemistry occur that prevent a caster-assigned heat from being processed.

When heats assigned to the caster cannot begin casting or cannot be completed, the full or partial heats must be rescheduled to other casters or platforms. If heats currently in process are scheduled to a caster or platform that will no longer be available due to changed conditions, and a re-assignment cannot be made, BOF production is delayed.

Final complications arise from the fact that a caster only processes one specific type of product; slabs, blooms, or billets, in a specific dimensional range. Therefore, a pre-determined balance of caster and platform production must be maintained based on anticipated product mix.

Are casters worthwhile? The answer is yes, they are. Ingots must be permitted to cool before they are stripped from the mold. They are then reheated for rolling into the shapes which the caster produces. This results in yield losses caused by crop ends, which are the unuseable tops and bottoms of the ingots, or the side and ends of rolled slabs and billets. Energy, material, labor, and facility dollars are saved when steel is continuous cast.

SUMMARY OF INTERACTION

All of the facilities and facility interactions mentioned here are recognized in iron and steelmaking simulation models. The best way to summarize this part of the presentation is to outline summary output statistics used in simulation reports. (See Figure 1)

Figure 1

I. **Annual Liquid Steel Tons Produced**

- Cast
- Teemed — Scheduled
  - — Diverted
- Total

II. **Heats Per Day** — **Cast** **Teemed** **Total**

- Mean
- Minimum
- Maximum

III. **Average Tap-to-Tap Minutes Per Heat**

- Delay — Intitial Assignment
  - — Scrap Availability
  - — Hot Metal Availability
  - — Wait to Blow
  - — Caster Synchronization
  - — Platform Scheduling
  - — Tap to Charge
- Vessel Cycle
- Total

IV. **Percent Utilization**

- Cranes — Scrap
  - — Charging
  - — Teeming
  - — Caster
- Platforms
- Caster — Operating
  - — Idle
  - — Planned Maintenance
  - — Turnaround (Breakout)
    - (Other)

V. **Average Caster**

- Heats Per String
- Hours in Ladle
- Tons Per Cast
- Strand Starts Per Heat
- Strands Completed Per Heat

VI. **Percent of Caster Diversions by Cause**

- Arrival — Too Early
  - — Caster Down
  - — Ladle, Temperature or Chemistry Problem
- Other — Lost Temperature
  - — Strand Loss

DATA AND PREMISES

Simulation models of iron and steelmaking facilities consider additions to existing plants as well as new plants. In the case of the former, existing data is collected, analyzed, fitted to a distribution, tested, and adjusted to reflect proposed changes in operating levels or practices. In the latter, the model is generally at the mercy of Engineering, Operating, and Metallurgical personnel when data is prepared. However, prior experience with facilities similar to those being considered generally provides a starting point for the development of data.

Development of a simulation model with this level of complexity requires a great deal of interaction between the modeler, Engineering, and plant personnel. In order to stimulate the type of responsiveness required, the models frequently develop in stages. For example, a model of the BOF/pitside operations may serve as a starting point. In this manner, Engineering and plant personnel can see that model development is progressing. It also supplies the opportunity for constructive critism as the project progresses, which minimizes the chance of full scale rejection of model validity at the completion of the project. In essence, those who must "live" with the final decisions made become full scale participants in the development of the data, facilities, and operating practices built into the model.

Having a critical and sensitive nature, virtually all of the data and premises employed in the simulation study are published in the final report.

THE MODEL

At this point, it is clear that the level of uncertainties, interdependence of facilities, and the dynamic nature of iron and steelmaking facilities precludes analytical solutions to the problems studied by the simulation model. An event scheduling model, using Q-GERT (1) is the basis of the models developed for the facilities. Q-GERT offers a network approach to simulation that provides a solid basis for defining individual production cycles within a facility, as well as sequentially dependent intra-facility events. This simulation language also provides the modeler with the ability to supplement the network flow with Fortran user functions when an event occurs. At these points, the modeler can incorporate complex decision rules and data storage which cannot be accomplished in the network.

The most critical and complex facility interaction is that of the BOF and continuous caster. As presentation time is limited, only this facet of the simulation model will be explained in more detail. Basic flow charts will be presented to illustrate the network flow. Fortran user function inserts will be discussed at their point of occurrence in the network.

Before discussing the network, three storage arrays employed in the model are presented to provide a basis for understanding how caster data is input and maintained. The first array is basically static and contains the caster product orderbook to be produced. Each row in the array represents a different product, while stored information includes the following:

- Product identification;
- Maximum string size permitted;
- Minimum casting rate permitted (tons/hour);
- Maximum casting rate permitted (tons/hour);
- Total number of heats to be produced; and,
- Total number of heats already produced.

The second array is a one-dimensional, dynamic file for the caster, which tracks the current product being produced. Information includes the following:

- Product identification;
- Number of heats remaining to cast this string;
- Number of heats remaining to schedule this string;
- Number of strands operating;
- Number of strands;
- Minimum number of strands to operate;
- Number of heats cast this string; and,
- Number of heats waiting to cast.

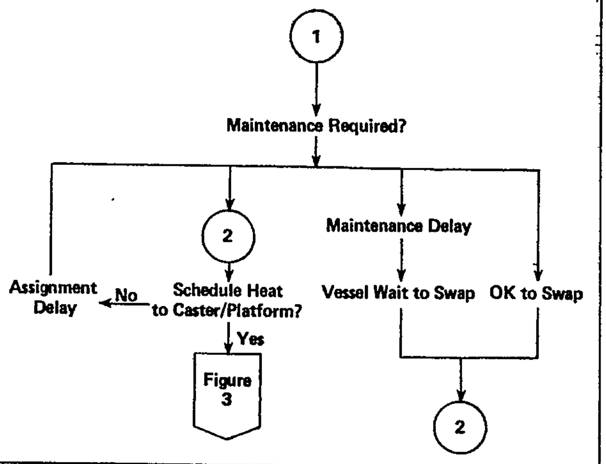
The final array is also dynamic. It provides the information necessary to track the projected caster status. Rows represent heats scheduled to the caster in order of expected arrival. Data includes the following:

- Heat sequence number;
- Heat identification;
- Expected arrival time; and,
- Expected completion time.

Having provided the basis of information flow, we proceed to the network and user functions. The network illustrated recognizes a three BOF vessel, one continuous caster shop, where two vessels operate while one vessel remains idle or receives maintenance. A limited oxygen supply prevents both operating vessels from blowing simultaneously. The first point of discussion centers around the vessel cycle and the initial scheduling of heats. When a vessel is ready to charge, a user function is called to schedule the heat to the caster or a platform.

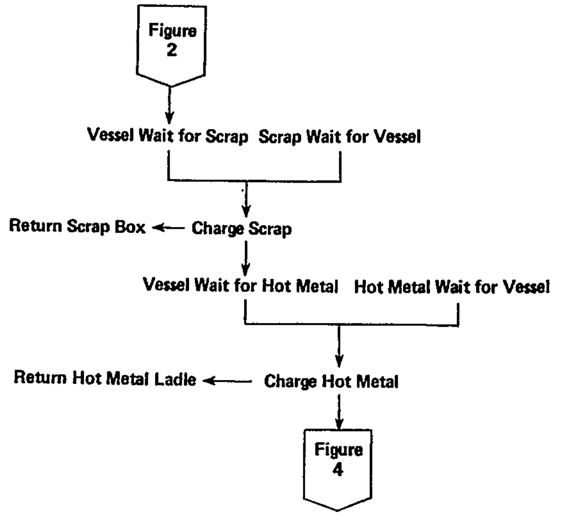
The user function first determines the caster and current product scheduling status. If the caster is available, and the current string is not completed, timing is checked. This is done on the basis of expected time of arrival at the caster, and expected time of completion for the last heat scheduled to the caster. If the heat is not expected to arrive at the caster too early to complete casting within the time in ladle limitation, or too late for arrival prior to completion of the last scheduled to cast, it is assigned to the caster. Otherwise, it is assigned to a platform or delayed. (See Figure 2)

Figure 2



When the heat receives an assignment, the vessel is ready to charge. If scrap is available, the vessel is charged; otherwise, it awaits the arrival of the scrap box. When the scrap is charged, a similar process occurs for the hot metal charge. (See Figure 3)

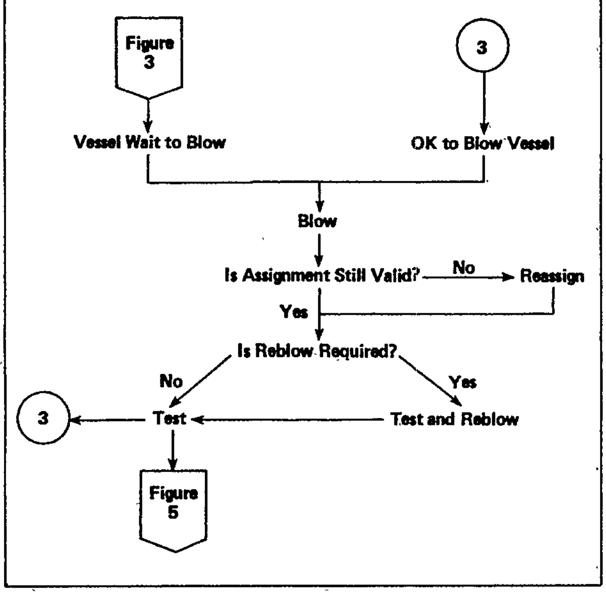
Figure 3



Completing the charging cycle, oxygen blowing begins immediately if capacity is available. If not, the vessel waits for oxygen availability. After the blow is completed, a user function is called. The user function checks heat assignment validity based on updated expected arrival and completion times. If the assignment is no longer valid, the heat is re-assigned to a platform.

Proceeding through the vessel cycle, a probabilistic network branch determines if a reblow is required, or if the heat tests "OK". Upon final test and approval, oxygen becomes available for another vessel. (See Figure 4)

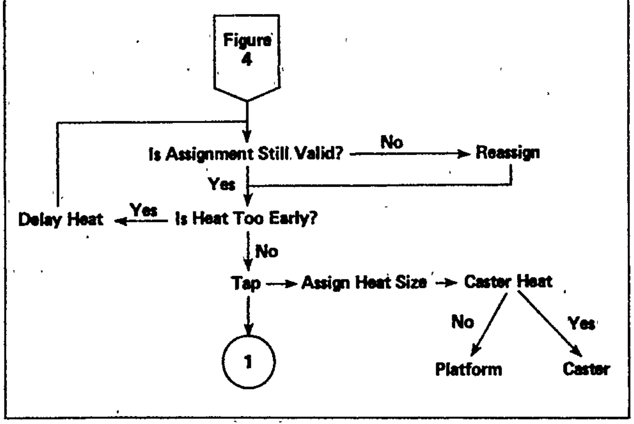
Figure 4



A user function call again checks assignment validity using updated information. If a caster heat is too early, vessel and caster operations are synchronized by delaying the tap of the heat. If a platform is not available for an ingot heat, operations are also synchronized by delaying the tap.

When operations are synchronized, the heat taps and heat size is assigned. Transfer of the heat to the platform or caster is initiated. (See Figure 5)

Figure 5

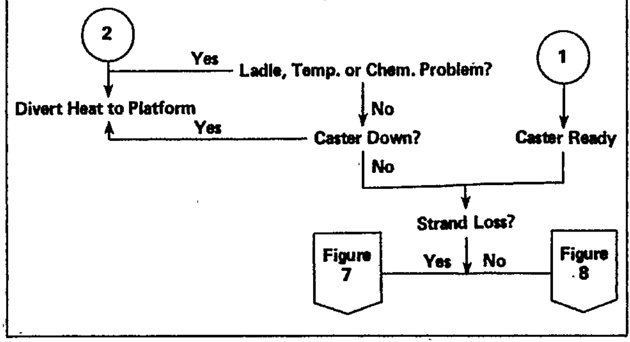


The vessel will take required maintenance or continue operation based on the results of a user function. If maintenance is required and an idle vessel is available, the vessels are "swapped". (See Figure 2)

When a heat arrives at the caster, a probabilistic network branch determines if the heat incurs ladle, temperature, or chemistry problems which prohibit casting. Where no problems are encountered, a user function is called to determine caster status. Transit delays may have resulted in late heat arrival, or the caster may have experienced maintenance problems. If the caster is still available, the heat waits for the caster to complete pouring the ladle it is designated to succeed. Heat schedule information is updated.

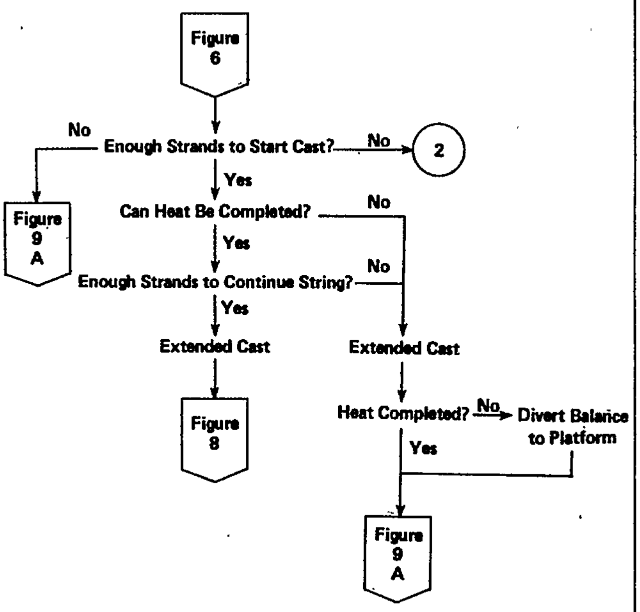
Now that the heat is ready to begin casting, it will follow one of two basic paths. A user function determines if, how many, and when strand losses occur. The first path discussed is the one taken when strand losses are incurred. (See Figure 6)

Figure 6



A subsequent user function first checks to see if any, part, or all of the heat can be cast based on the number of strands at start cast, the number of strands lost, time of strand loss, and adjusted casting rates. If the heat cannot be cast, the user function diverts the heat for platform assignment and revises the caster status to indicate that maintenance is required. Heats that cannot be completed are cast until the limitations on casting time or time in ladle are reached. The remainder of the heat will be re-assigned to a platform, and caster status is revised. When the heat can be completed, the user function determines if there will be enough strands to continue the string of heats. If the string can be continued, heat schedule information is revised. (See Figure 7)

Figure 7



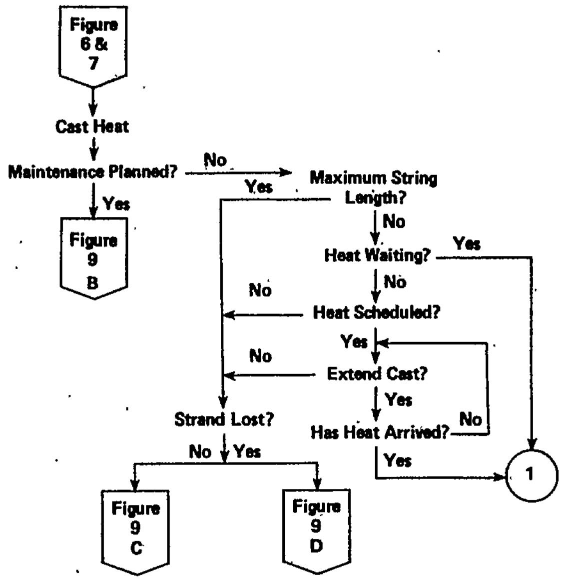
When strand losses have been experienced, planned maintenance is not due, and a string is terminated; a user function determines the cause of strand failures, which affects maintenance time. (See Figure 9)

The second path is taken when no strand losses occur, or when losses were encountered but string continuation is permissible. In this case, "continuous-continuous" casting is attempted. After the heat schedule is revised and the minimum time required to cast the heat has passed, a user function is called. If planned maintenance is scheduled, the string is terminated; otherwise, a check is made to see if the maximum string size has been reached. If so, the string is terminated. If not, and a heat is waiting at the caster, casting continues with the new heat.

When no heats are waiting at the caster, but a new heat is scheduled to arrive, timing is checked. The casting time is extended to synchronize completion of the cast with the expected arrival of the next heat as long as casting or time in ladle limitations are not exceeded. This process is repeated until the heat arrives and the string continues, or until limitations are reached and the string is broken.

When the string is broken, a user function decides if special maintenance is required to prepare for a new product width, or if a simple rethread is required. (See Figure 8)

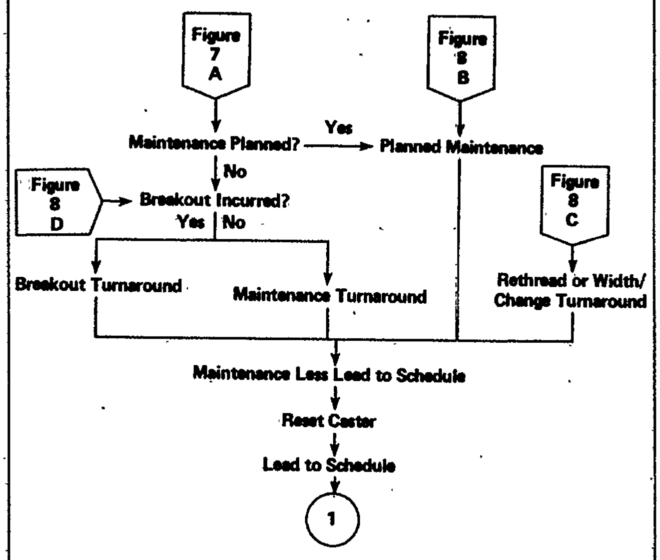
Figure 8



Approximately one hour prior to the completion of caster maintenance, caster storage arrays are reset or revised to recognize the new string's restrictions. Heats are then permitted to be scheduled to the caster. (See Figure 9)

Facility Planning Simulation Model (continued)

Figure 9



EXAMPLES AND CONCLUSIONS

Iron and steelmaking simulation models are providing solutions to numerous problems. Time prohibits a description of all the problems successfully resolved; however, a few examples were selected to illustrate this point.

When a capital expenditure project involving increased capacity arises, one of the questions posed is: How many torpedo ladles are required to prevent an iron transportation bottleneck? Answering this question involves the full development of the shop model, followed by repetitive runs of the model with a varied complement of ladles. In this manner, the simulation output of shop production versus number of ladles facilitates a return on investment analysis.

In multiple strand casters, a decision to continue a string after one or more strands have failed offers an operating practice problem which has been resolved using simulation. For example, assume that a caster has four strands, and the casting of a heat is in progress when one strand fails. One of three decisions can be made: casting can be terminated immediately, and the remainder of the heat is then diverted; casting could be continued until the heat is completed at the reduced casting rate, at which point maintenance is incurred to restore the lost strand; or not only can the heat be completed, but subsequently scheduled heats can also be cast until the string breaks. Determining the production potential of each philosophy is a matter of relatively simple logic changes in the user functions described for Figure 7. Are there enough strands to start casting? Can the heat be completed? Are there enough strands to continue the string?

A critical factor in caster productivity is both the minimum and maximum casting rates in terms of tons per hour. Minimum casting rates are established by the number of strands in the caster, product type, and caster design features. Maximum casting rates are determined by the number of strands in the caster, cut-off rates, solidification rates, and other design factors.

The effect of maximum rates on productivity are self-explanatory. Minimum casting rates, however, are also highly significant. Each time a string is broken, maintenance is incurred. Thus, the longer the string, the lower the percentage of maintenance delays. The lower the minimum casting rate, the easier it is to increase string size. This was evident in Figure 9, where it was demonstrated that heats extend casting, or synchronize with BOF operations, by reducing the casting rate to permit arrival of succeeding heats prior to completion of the current heat.

These factors are highly significant in problems where a decision between a single or a dual strand caster, etc., is being made. While the dual strand casters will probably be designed with a higher maximum casting rate, minimum casting rates may also increase.

Having presented a description of iron and steelmaking facilities, their interactions, data and premise philosophy, and modeling itself; some concluding remarks will be made.

All major iron and steelmaking facility projects are now analyzed using simulation models. Individual facilities can cost as much as one hundred million dollars. Prior to simulation, new facility and facility expansion decisions were made on the basis of the best analytical estimates available and the experience and judgment of decision-makers. Simulation has not replaced the experience and judgment of decision-makers, but it has provided statistically valid solutions where solutions had been so elusive in the past.