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A Simulation for the Justification and Planning of a Continuous Slab Caster

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ABSTRACT

Two major simulation models were developed to aid in planning the multi-million dollar expansion of steelmaking facilities at Bethlehem Steel's Sparrows Point, Maryland, plant. One model looks at the flow of liquid metal through steelmaking facilities while the second model represents the handling of solid slabs produced by the new continuous caster.

Both simulation models were written using "Bethsim", a Bethlehem Steel developed simulation language used primarily for discrete event simulation. Bethsim uses a network combined with user written FORTRAN subroutines and package subroutines that aid in the modeling of complex manufacturing elements such as roller lines, crane movements, and storage areas. Output from the models consists of standard Bethsim reports and customized reports produced by FORTRAN subroutines and a SAS postprocessor.

SPARROWS POINT PLANT

Bethlehem Steel Corporation's Sparrows Point plant is located 12 miles from downtown Baltimore along the Patapsco River near the Chesapeake Bay. There, steel is produced from raw materials and then processed into finished products. Major products shipped from this plant include hot-rolled sheet, hot-rolled strip, cold rolled strip, tin mill products, and plate.[1]

In line with Bethlehem Steel's commitment to a modernization program, a decision was made to expand the steelmaking facilities at Sparrows Point with the addition of a continuous caster. In June of 1983, the board of directors authorized the construction of a 2.9 million ton per year slab caster at Sparrows Point, to be constructed under the design of Voest-Alpine International Corporation. This was part of a $540 million financial program to install the caster at Sparrows Point and #2 slab caster at Burns Harbor, including other related facility improvements. The Sparrows Point caster is scheduled for start-up in the first half of 1986.

WHY A SIMULATION MODEL WAS DEVELOPED

When Bethlehem Steel decided to progressively upgrade and modernize its steelmaking capability, it embarked on one of the most ambitious and complicated efforts in its history. Several major factors had to be considered in order to properly incorporate a modern steel producing facility such as a continuous caster into existing operating plants. For example, some of these factors are:

* Preventing bottleneck areas that would affect production.
* Recognizing the need for and the impact of improvements to existing facilities.
* Maximizing the use of both existing and planned facilities.
* Testing the capacity, design, and flow of of the new equipment.
* Evaluating the effect of operating and scheduling policies on flow and production.

The complex interaction of these factors makes it impossible for an engineer or manager to manually analyze the problem. Fortunately, we at Bethlehem Steel have developed in-house skills required to create realistic computer simulation models that enable management to see how such a complex process will operate long before it is constructed and before large sums of funds are committed. It becomes clear that when a major industry such as steel knows that it must modernize and at the same time cannot afford to misspend any funds, a tool such as simulation is not just nice to have; it is essential.

AN OVERVIEW OF PART OF THE STEELMAKING PROCESS

In order to understand how our simulation model works and why it was created, it is important that one first understand the basic steelmaking operations and a little about how they work. Steelmakers use terms such as "teeming", "casting", "BOF", "slabs", and many other terms that are generally not familiar to anyone outside of the industry. We'll start with a quick description of some of the basic processes.

Basic Oxygen Furnace - BOF

Today in this country a large amount of steel is made by what is known as the BOF process. Liquid iron and solid steel scrap are placed into a large vessel that resembles a giant crock pot. Here intensive heat is generated by large amounts of oxygen blown into the furnace through a lance to refine a "heat" of steel until the right temperature and chemistry are obtained. When the heat is ready, it is poured, or "tapped", into a large ladle. It is during this process that alloys and other ingredients are added or adjusted as they are needed. The liquid steel is then transported to the next process, teeming or casting, to solidify.

Teeming

Ingot teeming is a labor intensive process that has been used for decades in the steel industry. After liquid steel is poured from the steelmaking vessel into large ladles, huge cranes transport the ladles to an area where several ingot molds have been arranged on strings of railroad cars. The crane holds the ladle while the steel pours into awaiting molds. This pouring process is known as "ingot teeming". After the liquid steel cools in the mold, the mold is then removed ("stripped"), leaving a solid ingot of steel that must be reheated before being made into a slab or bloom in the next step of the steelmaking process.

Casting

Again a crane is used for transporting a ladle of liquid steel to the casting machine. The casting machine is a massive, complex piece of equipment that may be 600 feet long, five stories high, and cost millions of dollars.

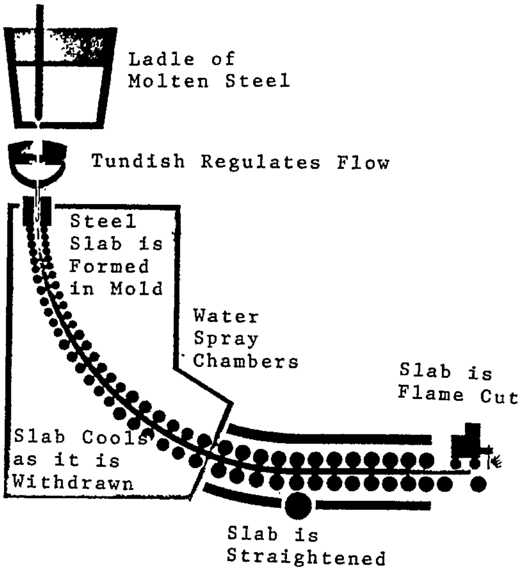

Figure 1: The Casting Process

In the casting operation the crane places the ladle on the casting machine turret where the hot steel is allowed to flow into a large bathtub shaped container known as a tundish, shown in Figure 1. From the tundish the liquid steel is directed through a nozzle into the water-cooled mold of the caster. "When molten steel comes into contact with the walls of the water-cooled mold, a thin solid 'skin' forms."[2] Once the solid skin has formed in the mold, the steel moves through a series of water-cooled rolls as the core of liquid steel solidifies. "The thickness of the skin increases as the casting moves downward, and, eventually, the entire section is solid."[2] As the steel solidifies it goes through a series of bending rolls and then a straightener so that it is moving in a horizontal position. As the solid steel proceeds horizontally across the roller beds, a torch attaches itself and moves with the strand, cutting the cross section to form smaller segments known as slabs.

A continuous slab of steel will be cast as long as liquid steel arrives on time at the entry end of the process. Naturally there are times when desired changes to size or scheduled maintenance will dictate that a cast be terminated and a new cast started.

Advantages of Casting

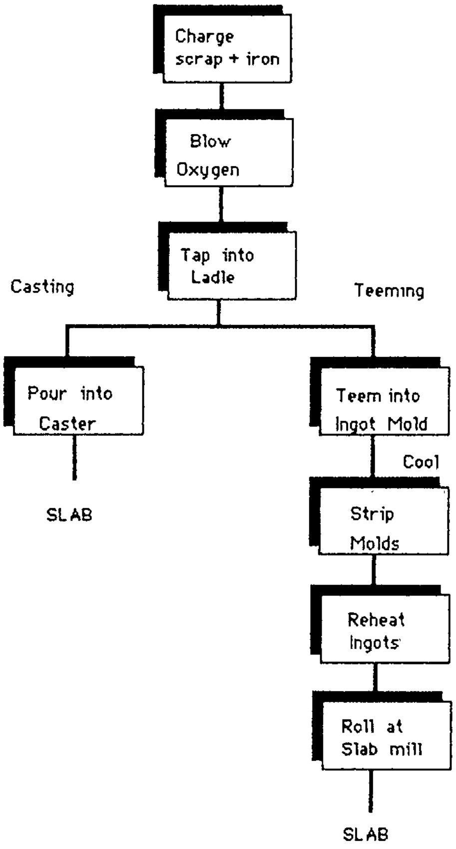

Figure 2: Comparison of Casting and Teeming

Obviously, producing slabs by the casting process has several advantages over the multiple steps involved in the teeming process. As seen in Figure 2, the casting process is much quicker and eliminates the need to roll ingots through a slabbing mill. The time and energy costs associated with heating ingots in the soaking pits are also eliminated. The yield from liquid steel to slab is significantly greater using the casting process. Also, slabs produced through the caster are more uniform and often of better quality than teemed slabs. As this fact is recognized by customers, the demand for cast steel increases.

Caster Simulations

With the commitment to major capital expenditures, management directed that a simulation model be used in the decision-making process for caster design and justification. This was not a new concept for management of Bethlehem Steel. The currently operating caster at Burns Harbor was simulated extensively, and a simulation model of the new caster at Steelton plant was used prior to its late 1983 start-up to evaluate design concepts and operating schedules. Both of these models were constructed using Bethsim, our in-house-developed simulation language.

BETHSIM

Bethsim is an adaption of the SLAM simulation package developed by A.A.B. Pritsker and C.D. Pegden. Several modules were added to gear the language toward steel plant simulation problems and to allow easier input and output of data. Bethsim is used primarily for discrete event simulations and is a network flow oriented language. Event nodes allow access to user written FORTRAN code or to the extensive list of subroutines and functions available.

Bethsim Features

With the creation of several simulation models at Bethlehem Steel, we noted a common need to simulate particular functions inherent to the steelmaking industry. Many of these functions involve material handling operations that are used in several places, such as the operation of cranes on runways. The Bethsim diagram in Figure 3 shows modules that were developed for these functions. They include cranes, roller lines, piling logic for areas, and batch processing of several objects.

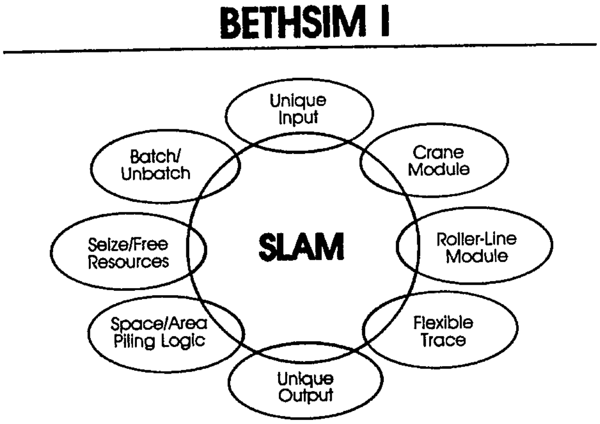

Figure 3: Bethsim Features

The crane module facilitates the modeling of the movement of transactions from one location to another by crane. From the input of crane velocities and hoist speeds, travel times are calculated, including interference with other cranes in the same runway. Similarily, a roller line module facilitates the modeling of both unidirectional and bidirectional roller lines. The roller lines are broken down into seizable sections with look ahead capabilities to prevent blocking.

Bethsim also allows for the seizing of spaces, or areas. Each area can be broken down into several piles, each with its own capacity. Sixteen different piling logics are available for choosing where to place a transaction.

The batching capability is another useful characteristic of Bethsim. Several transactions can be combined to form one transaction. After being processed as a single transaction, they can later be unbatched to their previous individual characteristics.

The output options provided within Bethsim are another added feature. Detailed information on crane, resource, area, and file statistics automatically appears. At the user's request, traces can be produced of an isolated section of the network or of particular transactions as they flow through the network.

THE BOF SHOP MODEL

In the fall of 1981, the Home Office Operations Research group was requested to build a simulation model of the BOF shop at Sparrows Point. The purpose of this simulation was to measure the impact of certain facility and material flow changes that would occur in preparation for the installation of the continuous caster. It was anticipated that a model of the caster would eventually be constructed and linked to the BOF model for an overall simulation of steelmaking.

BOF Cycle

The BOF shop is a large building containing two vessels that are designed to process approximately 250 tons of molten steel to a temperature of over 2900 degrees F. Large containers of scrap steel are delivered to the building by railroad cars and their contents are lifted and dumped into the BOF vessel. Two cranes load (charge) these vessels by delivering ladles of liquid iron which are poured into the BOF vessel. Charging is followed by the blowing of oxygen into the iron and scrap mixture through a lance that is lowered into the vessel. After a 15-minute refining period the steel is sampled and then poured into a waiting ladle under the vessel. Figure 4 displays a layout of the shop.

In addition to servicing the BOF vessels, cranes perform several tasks, such as the handling of empty ladles, empty scrap boxes, and full pots of slag. At times cranes suffer mechanical breakdowns, and the BOF vessels can experience numerous types of delays in the course of the normal steelmaking cycle. These delays are captured as random occurrences in our model to accurately represent the real world of steelmaking. In addition, the model must imitate the scheduled maintenance on both the cranes and the vessels.

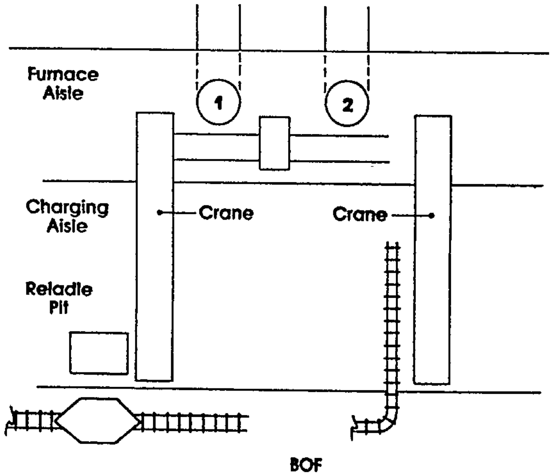

Figure 4: Layout of the BOF shop

Modeled Activities:

- * BOF Cycle
  - Scrap Charge
  - Hot Metal Charge
  - Blow
  - Sample
  - Reblow (If required)
  - Tap
  - Slag Off
  - Random Delays
- * Crane Activity
- * Ladle Activity
- * Vessel Swing (Pattern for using vessels, including down time)

Questions Answered

Several studies were made of the activities simulated in the BOF shop. These studies include:

- * Affect on production and ladle activity of a station to treat the hot iron in the ladles.
- * Affect of different heat sizes.
- * Affect of increased oxygen blow rate on BOF and caster production levels.
- * Affect of different vessel swing patterns on shop activity and production.
- * Impact on production with 1985 conditions of larger heat sizes but no caster.

CASTER MODEL

With the completion of the BOF model, we began modeling the proposed caster. The primary purpose was to determine if the production level desired by management could be achieved. Although it was known that the machine was capable of this level of output, there was concern that material handling difficulties might cause bottlenecks that would impede delivery of liquid steel to the caster. The planned location of the caster dictated that cranes needed for teeming would also be required to deliver ladles to the caster building in a timely fashion to prevent caster disconnects.

Simulated Ladle Activity

Figure 5 shows the layout of the teeming aisle and caster building. The simulated activities of these areas were incorporated into the BOF steelmaking model, starting with the delivery of the ladles of liquid steel from the vessels to the teeming aisle. Here three cranes are busy delivering ladles to the caster, teeming steel, or handling the numerous "odd jobs" that are required to keep the shop operating. The operations people in the teeming aisle must make intelligent choices on when to use which crane or teeming platform in order to avoid interference or congestion. Our model had to be programmed with decision making logic to make the same choices by looking at all the action that is taking place, not only in the teeming aisle, but also in the BOF shop and the caster building.

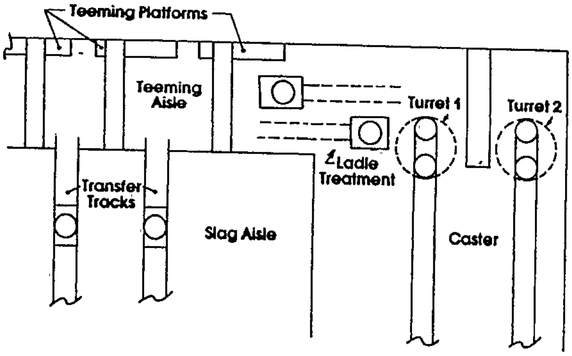

Figure 5: Layout of the Teeming Aisle and Caster Building

Ladles going to the caster from the teeming aisle travel on transfer cars. A single crane in the caster building services the two casting strands, handling both full and empty ladles. Priority is given to getting ladles to the caster in order to prevent missed connections, and the casting speed is adjusted for this purpose. Casters are subject to breakouts ("a rupture of the skin below the mold, releasing molten steel")[2], aborted heats (halt of flow of steel from the ladle), and missed connections, all which require sending ladles back to teeming and restarting the strand.

Modeled Activities:

- * Ladle Activity
  - Teeming or Casting

  - Heats Diverted to Teeming
  - Maintenance
  - Availability for Tapping

* Crane Activity
* Teeming Stage Activity
* Transfer Car Activity
* Breakdowns and Maintenance
  - Cranes
  - Transfer Cars
* Caster
  - Speed Adjustments
  - Breakouts, Aborts, Missed Connections
  - Turnarounds, Mold Changes, Maintenance Turns

Questions Answered:

Some of the questions answered in this area of the model include:

* Ability of caster to achieve planned production level.
* Impact of various scheduling practices on caster output.
* Ability of the upgrading of a teeming crane to relieve teeming aisle congestion.
* Average time (corresponding to heat loss) between tapping and casting.

PERFORMANCE FACTORS

Alternative runs for the various cases were judged on several major performance factors. The two most important were BOF yearly tonnage and caster yearly tonnage. Other results stressed in evaluating flow and operating alternatives are as follows:

AREA	PERFORMANCE FACTOR
BOF	- Annual tonnage Cycle time Hot-metal delays on furnace Ladle delays on furnace Charging crane utilization
Teeming aisle	- Teeming crane utilization Teeming stage utilization Transfer car utilization Treatment station utilization
Caster	- Caster crane utilization Caster annual tonnage Caster utilization Heats per sequence (consecutive heats without breaking the strand) Ladle tap to open time Casting minutes per heat

MAJOR STUDIES

The simulation model was run with several different numbers of steel ladles to determine how many would need to be purchased to prevent delays of the BOF while waiting for a ladle. This included varying the number of ladles "on the run" (ladles in use, cycling from BOF to caster) and the number of ladles "off the run" (ladles under repair). The simulation results supported the purchase of 14 ladles with 7 of these on the run.

A major concern was the location of the station for treating the molten steel in the ladles before it arrives at the caster. One plan was to treat the steel on the transfer cars after they had entered the caster building; the other alternative was to build a special stand in the caster building and place the ladles there for treatment. Runs made under planned operating levels with varying treatment times showed that the treatment on the transfer cars was preferable based on transfer car and crane utilizations.

In spring of 1984, two major facility installation projects were considered in connection with improving steelmaking and planned caster throughput. First, a ladle furnace was proposed to be installed to reheat steel in the ladles and prevent caster disconnects from ladles that are too cold to cast. Runs of this scenario showed an increase in caster output of approximately 6.7%. A sensor lance was also under consideration to take temperature and chemical readings at the BOF and reduce sample time. Simulation runs showed an increase in BOF tonnage of approximately 12.8% and a resulting increase in caster output of 3.7%. The simulation results of the effect of these two facilities were used in the justification reports presented to top level management.

SLAB HANDLING SIMULATION

SHOP LAYOUT

An additional simulation model involved the handling of cast slabs and their subsequent shipment by rail. The slabs are separated from the strand by burning and enter the simulated area on one of the caster runout tables. The slabs are then pushed onto a piling table by a mechanical drag. When a pile of slabs is complete, an overhead crane moves the completed pile from the piling table and loads it onto an awaiting railroad car. When a series of railroad cars are loaded, the railroad shifts a new set of cars into the crane run.

RESULTS REQUIRED FROM THE SIMULATION

The purpose of the simulation model was to provide answers to the following questions:

* What is the utilization of the overhead crane and what benefits are achieved by the addition of a second crane into the system?
* How many piling tables should be purchased and what is their arrangement?
* How does a different casting schedule affect the handling of the slabs?
* What affect do crane breakdowns have on the slab handling system?

MODEL CONSTRUCTION

The model logic was developed from discussions with engineers and technology personnel at the Sparrows Point plant and home office professionals. The main purpose of this step was to understand the product flow and to minimize the possibility of modeling a system that did not emulate the proposed system. The logic was then programmed using the Bethsim simulation language.

One of the requirements of the model was to analyze the number and placement of piling tables on each caster strand. The decision was made to develop a single model making use of user-supplied variables to indicate the desired condition of the system. By using this technique, the model became flexible in design. A change in these variables changed the operation of the simulation. This become important during the evaluation of the number and placement of the piling tables in the system. Other input parameters were documented and distributed to the engineers at Sparrows Point and home office for verification. This list of variables was also included in the simulation output reports. During the programming of the program logic, the physical location of these variables were noted for ease in the modification of the variables.

Piling logic was not finalized during the development of the simulation model. This logic involved the determination by the system when a pile of slabs was complete and should be moved from the piling tables. One case involved loading each table to its capacity and to rearrange the slabs in the railroad cars. Another case involved the calculation of the optimum number of slabs for each slab size and to move the piles when that number was reached. The different piling logics were placed in separate subroutines for use while executing the simulation model.

MODEL VALIDATION AND VERIFICATION

The simulation model was verified using simulation traces installed into the subroutines. The product flow through the model was validated and approved by Sparrows Point personnel. Since the facility was not in operation and no actual data was available, home office personnel compared the simulation results with calculations performed manually. The model was approved as representing the actual conditions of logic and timing.

MODEL OUTPUT

The initial case studies using the model involved the different arrangements of the piling tables on each caster. These studies were used to evaluate the impact that the additional piling tables has on the system. For the initial case studies, all of the input factors were held constant. The model results were summarized and presented to Sparrows Point personnel.

Additional information was requested by Sparrows Point engineers regarding the state of the system during the simulation runs. The requests were two fold:

- What impact does a different schedule have on the system?
- What impact do crane breakdowns have on the system?

The initial model was modified to implement the requests. A new front end was installed on the model that read the caster schedule from an input file which contained scheduling information and the distribution of BOF heats per strand. Following the attachment to the simulation, supervision had the flexibility to analyze the problem areas in a particular schedule. The crane breakdown request was handled in an unique manner. Instead of simulating a crane breakdown and subsequently changing the simulation, random times were selected during the simulation to take a snapshot of the system. When a breakdown occurred, the program calculated the amount of time available to repair the crane without having to stop the casting process. The time was stored and the simulation was allowed to continue without modification. The crane breakdowns were scheduled frequently and a post processor written using SAS was used to summarize the data. Additional statistical analyses were performed using the output information generated by the simulation.

One additional question had to be resolved:

> What effect does a second crane have on the product flow in the system?

A second crane was modeled and case studies were run that paralleled the simulations involving only one crane. Analyses were performed to evaluate the effect of the second crane and reports sent to Sparrows Point and home office personnel for their evaluation.

The time required to build the slab handling simulation model and to run the 14 case studies requested was five weeks with an additional week for project documentation. Subsequent to the completion of the model, additional studies have been run involving modifications to the input parameters described earlier.

From the initial model of the BOF shop, the liquid steel simulation has spanned almost three years of planning. In that time there have been several changes to both current practices and facilities and plans for the new facilities; the model has had to keep up with these changes. As new studies are conducted and new facilities proposed, management at Bethlehem Steel continues to turn to the simulation models in recognition of the valuable information they can provide.

Reference

1. Bethlehem Steel Corporation, Sparrows Point Plant, Booklet 3216.

2. McGannon, Harold E., The Making Shaping, and Treating of Steel, Eight Edition, United States Steel Corporation, USA, 1964 pp. 664-665.