Simulation Analysis of a Steelmaking Facility

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ABSTRACT

During the planning of new production facilities, many questions arise regarding the facility's capabilities and operation. When the plans involve new manufacturing technology, answers to these questions could be both important to the decision making process and difficult to obtain. Simulation can be an effective means of providing the necessary information.

This paper describes a simulation model that was developed and used to evaluate the uncertainties associated with a proposed steelmaking facility. The model provided answers to questions about the facility's output capabilities and the degree to which it would interface with existing operations. Although the model was developed to answer specific planning questions, potential applications can be identified in both facility startup activities and full-scale operations.

INTRODUCTION

Facilities planning is a process in which most competitive manufacturing firms become engaged at some time or other. This process encompasses the activities of identifying, evaluating, and selecting from alternatives that either modernize existing capacity or expand capacity in anticipation of increased demand. Alternatives, of course, range from the relatively quick and inexpensive upgrading of bottleneck operations to the more elaborate and expensive construction of a completely new facility. Simulation can be a useful technique for evaluating either case, but its real value lies in resolving uncertainties associated with a major facility expansion, especially when the facility will use technology new to the firm.

To illustrate the use of a simulation model under these conditions, a recent project by the Operations Research Department at J. Ray McDermott Co. will be presented. The client for which the simulation model was developed is the steelmaking unit of a major manufacturing firm. As a leader in his field, the client spends a significant amount of time evaluating his external competitive environment as well as his internal manufacturing environment. Factors in the two environments initiated interest in the area of facility planning.

As noted above, the client identified several alternatives aimed at maintaining competitive manufacturing capabilities. The most significant alternative involved the construction of a modern steelmaking facility using advanced technology. Despite considerable efforts to collect information about the proposed operations, uncertainties about the capabilities of the proposed facility remained. To provide the client with information aimed at resolving these uncertainties, a model simulating the proposed operations was developed.

THE MANUFACTURING SYSTEMS

Before examining the model and its use, the two manufacturing systems involved will be briefly described and compared. By noting the differences that exist between the current and proposed operations, reasons for developing the simulation model will be better understood.

The steelmaking operations currently used by the client are shown schematically in Figure 1. These operations perform a very necessary function--they produce the steel bar stock required for the client's seamless tubing operations. The process begins by charging steel scrap into an electric furnace where the scrap is melted by heat generated from an electric arc. The molten steel is refined and brought to the correct chemistry while still in the furnace. At this point, the molten bath is transferred to a large ladle where it may be further refined by vacuum processing if necessary for the material grade being produced.

The molten steel is teemed, or poured, into ingot molds where solidification occurs. Each heat, i.e., a single molten steel bath, produces several

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ingots weighing between three and seven tons each; the actual number of ingots produced from a heat depends on the size of both the furnace from which it came and the size of the ingots being produced. Following solidification, the ingots are stripped from the molds and transferred to soaking pits.

The soaking pits are the initial stage of the blooming process. In these pits, the ingots are brought to a uniform temperature prior to being processed by the blooming mill. The blooming mill reduces the ingots into a more manageable rectangular cross sectional shape (blooms). The bloom is then cooled to room temperature, inspected and conditioned prior to further processing.

Blooms are reheated and processed into bar form. The bars are cut to desired lengths, cooled to room temperature, inspected, conditioned, and sent to the tubing operations.

The proposed facility [Figure 2] would begin with the same basic operations, i.e., melting scrap in an electric furnace followed by additional refining of the molten steel while in the ladle. At this point, however, the new operations become dissimilar. Some blooms would be produced by processing the molten steel through a continuous strand casting unit rather than the current teeming bay/ soaking pit/blooming mill sequence described above. The molten steel would be poured from the ladle into a tundish at the top of the casting equipment. The molten metal flows from the bottom of the tundish into a series of bottomless molds where a thin shell of steel solidifies around the molten metal. The gradually solidifying bloom continues to harden as it passes through further cooling zones. Finally, the strand of steel moves to a level table where it is torch cut to the required length.

In examining the schematic representations of the current and proposed operations, some differences should be apparent. The current process permits the steel to be cooled, temporarily stored, and reheated if downstream operations prohibit the smooth flow of material. In the proposed manufacturing operations, material must be kept moving (i.e., it cannot be allowed to cool and staged for later operation). Although processing time, material yield, and energy consumption are improved by the continuous flow, an alternative processing path is necessary. In Figure 2, the alternative path shows material being taken from the ladle refining unit to the existing teeming bay operations. Heats would be required to follow this alternative path under the following conditions:

- Delays in preparing the casting unit causes excessive holding times in the refining unit; heats will be teemed into ingots and processed in the conventional manner.

- Equipment failures during casting can prolong the time required to completely cast a heat. Once the casting time reaches a predetermined maximum, the remaining metal is diverted from the caster; the uncast molten steel will be scrapped or salvaged by pouring it into ingots.

FIGURE 1
CURRENT OPERATIONS

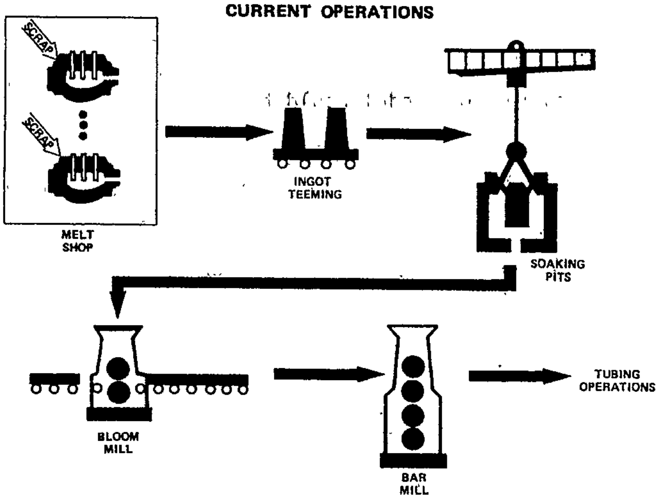
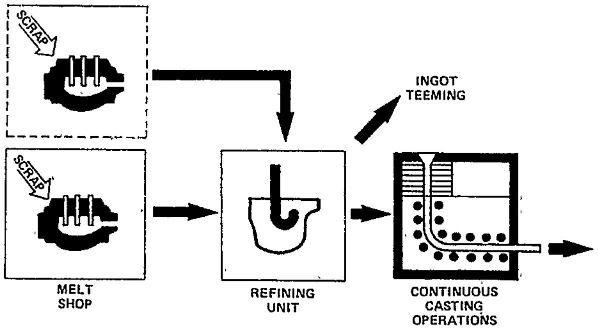


FIGURE 2
PROPOSED OPERATIONS



THE MANAGEMENT PROBLEM

Since the proposed operation was new to the client, some uncertainty existed about its performance. Could the facility meet target production needs? What would happen if a second furnace (shown in the dashed box in Figure 2) were included? How much material would be diverted from this facility to the existing teeming bay operations for conventional processing?

The client attempted to answer these questions by using an analytical approach. The average cycle time of the electric furnace and the continuous caster were estimated by starting with the normal equipment cycle time and adding in an average delay time per heat. In the case of a facility with a single electric furnace, the average cycle times were exactly equal. Although this condition makes it easy to estimate facility output, the answer is misleading. The estimate assumes that all production will pass from the furnace through the continuous caster. This assumption is unlikely to be true in the real case and provides no information about the extent to which current facilities will be needed for diverted material. Thus, the estimate made in this manner is only an estimate of the furnace output. Furthermore, adding a second furnace to the operation seems to complicate this analysis. Not only does the second furnace require the coordination of the flow from the two sources through the common equipment (the refining unit and the continuous caster), but it also presents the possibility of multiple heat casts. Timing, an important element in addressing these questions, cannot be adequately included in the analytical approach.

A simulation model would be more useful in providing management with answers to the uncertainties outlined above. Given the frequency of delays and their duration, as well as the designed operating characteristics of the equipment, a simulation model would better estimate the facility output along both paths, i.e., through the casting equipment (normal), and during diversion to the teeming bay (abnormal). In addition, the model, unlike the analytical approach, could provide the client with a tool to evaluate prospective operating policies prior to actual construction of the facility.

THE MODEL AND ITS USE

A discrete event simulation model was developed using SIMSCRIPT II.5. The model included the electric furnace operations, the ladle refining unit, and the continuous casting equipment described above. Later, the operation of the second furnace was included so that an alternative mode of operation could be evaluated.

The data used to describe the proposed operations came from a variety of sources: first-hand experience, firms with similar operations, preliminary design specifications, published statistics [1], and the model user. Since existing operations already used electric furnaces, this portion of the model was the easiest to construct.

The furnace processing time began with a fixed time determined by the activities performed during each heat, e.g., furnace inspection, electrode adjustment, scrap charging, melting, etc. This "normal" time was extended by the inclusion of delay times. Several delays were pre-defined by occurrence frequencies and duration distributions. The distributions were sampled to determine the delays, and their duration, that should be included for a given heat. Additional delays caused by the non-availability of downstream equipment were also tabulated, as they occurred during the simulation, and included in the overall furnace operation time.

Delays that increase furnace operating times are not the only delays that could influence the melting operations. Major furnace repairs occur in a definite cycle and involve a significant amount of time when required. These delays were included by progressing through the cycle from a randomly selected starting point. For example, assume that a major repair occurs every 100 heats. At the start of a sampling period, it might be determined that the next heat would be number 91 in the repair cycle. Under these conditions, the time between the tenth and eleventh simulated heat would reflect the time required for the repair.

Time required for normal casting operations was determined by using the proposed equipment's capabilities in terms of weight cast per minute and estimating the normal time to reset the equipment between heats of molten metal. Like the melting cycle, these normal times could be increased by anticipated equipment failures. Each of the individual strands of the caster could fail independently according to a prescribed probability and time-to-failure distribution. Not only could these failures alter the required casting time by reducing the number of operational strands, but some failures could also increase the equipment reset time by requiring additional cleanup operations.

Operating parameters for the intermediate refining process were not as stringently defined. Only a minimum time was specified. The maximum time, one of the operating policies examined by the model, was supplied when the model was executed.

Unlike the modelling of an existing manufacturing system, model validation could not be accomplished by using actual data. Instead, strong reliance was placed on non-quantitative techniques [2] requiring a strong analyst/client relationship. The model was developed in a modular fashion--each operation was modelled individually and reviewed with the client, using detailed output from the model. Once the individual operations were properly modelled, the modules were linked together and revised for possible timing problems. The client's expertise was essential in developing a model that would accurately represent the real-world system.

The model was used to examine a variety of cases. These test cases examined operating policies under the following modes of operation:

- Batch Casting uses a single electric furnace to supply molten steel to the continuous caster. After each heat is processed through the caster, the equipment is reset prior to accepting the next heat.

- Sequential Casting uses two, or more, electric furnaces to feed the continuous caster. Under this type of operation the caster would not be reset after each heat. Instead a maximum of three heats could be processed before resetting the casting equipment.

Under both modes of operation the central question was --How much production can be expected from the continuous casting equipment? In addition, the model would also aid in answering several secondary questions:

- How much material would be diverted to existing teeming bay facilities for conventional processing?

- What effect would the maximum ladle refining time have on caster output?

- How would caster operating policy affect sequential casting output?

- What would be the expected single heat/multiple heat mix during sequential casting operations?

Simulation statistics were collected on a "simulated week" basis. Weekly time periods were easy to define--all production during a given week would terminate prior to a maintenance period scheduled between weeks. Measuring the desired statistics on a weekly basis also yielded a larger sample for each case--300 independent time periods were examined in each case by randomly generating starting conditions in melt shop operations. The large sample size would not only give an accurate estimate of average output but also the manner in which this output is distributed between minimum and maximum levels.

MODEL RESULTS

The following tables present results from selected cases. The confidential nature of the results has made it necessary to index the results (100 = average cast tonnage produced in batch casting Case 2) and relate the amount of diverted, or teemed, material to the average amount melted in each case.

In Table 1, results are shown for two batch casting cases--Case 1 limited the holding time in the ladle refining unit to a maximum of 2 hours, while Case 2 increased this time to a 4 hour maximum.

Clearly, both positive and negative effects can result from increasing the maximum time that material can be held in the refining unit. Slight gains were noted in terms of cast tonnage, and significant improvements occurred in the amount of material sent to the teeming facility. But these improvements are not without trade-offs. The average time a heat is held in the ladle increased nearly 38%; an increase that could significantly impact on the life of the refractory material used to line the ladle. Operating personnel could now make an economic assessment of one operating policy versus the other.

A comparison of three cases involving sequential casting operations is shown in Table 2. These cases compare sequential casting operation policies. In Case 3, the caster would be reset if one strand, or more, is inoperable. The failure of half of the strands in Case 4 would require the equipment to be reset before continuing. In Case 5 the casting unit would continue to operate if as few as one strand were operable. From the case studies, it is clear that, as this operating policy is relaxed, improvements are made in nearly all measures of performance. However, the incremental improvements observed between Cases 4 and 5 are insignificant and may be negated by the increase in diverted tonnage, especially if it is assumed that the major portion of these diversions would be scrapped.

TABLE 1
BATCH CASTING RESULTS

	Case 1	Case 2
Cast Tonnage (Indexed)		
Minimum	78	82
Average	96	100
Maximum	109	115
Teemed Tonnage (Melted Weight, %)		
Minimum	2.4	0
Average	11.0	2.7
Maximum	22.4	9.4
Diverted Tonnage (Melted Weight, %)		
Minimum	.1	.3
Average	2.0	2.3
Maximum	4.8	5.1
Average Refining Hold Time (minutes)	70.6	97.3
Heats Reaching Caster (Heats Started, %)	87	97

TABLE 2
SEQUENTIAL CASTING RESULTS

	Case 3	Case 4	Case 5
Cast Tonnage (Indexed)			
Minimum	102	123	118
Average	123	142	145
Maximum	142	164	154
Teemed Tonnage (Melted Weight, %)			
Minimum	6.7	0	0
Average	14.7	6.1	4.0
Maximum	24.3	13.4	12.0
Diverted Tonnage (Melted Weight, %)			
Minimum	.2	.2	.2
Average	1.5	1.3	2.5
Maximum	3.5	2.8	6.4
Average Multiple Heat Casts (Total Casts, %)	30.6	54.6	61.4

MODEL BENEFITS

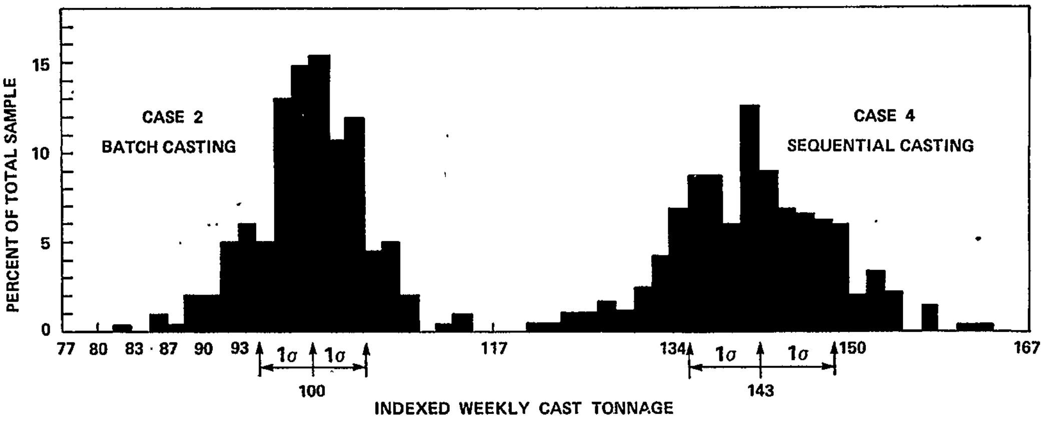
The benefits of developing a simulation model are not limited to the results and analysis presented briefly above.

Prior to the development and use of the simulation model, the client could only hypothesize about the capabilities of the proposed facility since he lacked direct experience with the technology to be employed. Following the test cases examined using the model, management was more confident in the capacities of proposed operations. The best illustration of this point is that, following the simulation studies, the plans for the operations considered by the model remained constant while other downstream operations which had not been considered underwent several changes.

The information obtained from the simulation model was largely unobtainable from other sources. "Educated guesses" would hardly have increased management's confidence in the plans. Firms operating similar equipment could have been consulted but it is unlikely that such information would be made available in the detail needed. Building and experimenting with the actual facility would, of course, have provided the most accurate, but costly, alternative.

Next to constructing the facility, the simulation model provided the most accurate estimate of the facility's production capabilities. Using the analytical approach, estimates of the average number of cast heats produced by the batch casting process exceeded the model estimates by approximately one standard deviation (as measured by the model). Although from a statistical point of view this difference may seem insignificant, one must consider the ultimate use of this information--the economic analysis of the project. An inaccurate estimate of production volume leads to an overestimation of economic measuring tools (NPV, ROI, etc.) by erroneously estimating cash inflows and net cash flows. The improved production estimates generated from the model thus play an important role in the decision making process when a project's economic status approaches the "cut-off" criteria, or when the project is one of several opportunities competing for capital investment funds from a limited pool.

FIGURE 3
DISTRIBUTION OF WEEKLY OUTPUT



Perhaps even more important are the output distributions obtained from the model. Figure 3 graphically shows the distribution of weekly ouput from Cases 2 (batch) and 4 (sequential). Not only does this figure demonstrate the relative importance of batch casting versus sequential casting operations, but it also presents data useful to the decision maker in other ways. This information can be used in conducting a risk and/or sensitivity analysis of the proposed investment, or in estimating the likelihood of meeting a desired target production level.

Finally, developing a model of the proposed facility establishes a base for future analysis during subsequent planning stages, facility startup, and full-scale production. Additional planning applications include the evaluation of equipment operating characteristics at the time of final design evaluation and the inclusion of downstream production operations. The latter was actually requested in 1978 when additional bar production facilities were being considered. These operations were added to the model and preliminary tests conducted to answer questions similar to those discussed above.

At startup, the model is potentially valuable as a training tool. Obviously, some simplifications were made in constructing the model, especially at points where individuals would actually make production decisions as required. Using a time-sharing computing system, the model could easily be modified to accept user supplied input at these points. By modifying the model in this manner, individuals selected for production management positions could be given the opportunity to gain some decision making experience prior to assuming this responsibility with the real facility.

Once full-scale operations have commenced, the product mix, a factor not addressed in this model, could impact the facility's capacity. If orders were not properly sequenced through the facility, the actual throughput could vary significantly from the planned production level. By enhancing the existing model, available scheduling alternatives could be analyzed without disrupting actual operations.

CONCLUSION

The results obtained from the model were well received by the client and useful in his evaluation of the proposed facility. Unfortunately, their accuracy will not be assessed in the near future because economic considerations have postponed the building of the new facility in favor of upgrading several areas of the existing operations. This should not detract from the modelling effort described above, however, since the model accomplished its goal of providing valuable planning data for the proposed facility, information that will still be valid when consideration of the facility is renewed.

Thus, while simulation is an established tool to analyze existing manufacturing facilities, it should not be overlooked when planning additional facilities, especially if they will use a totally new technology. Using a simulation model in the planning phase of expansion or modernization programs can provide useful insights and generate confidence in the proposed operations. Moreover, the established model can continue to be beneficial in future planning and operation activities.

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