SIMULATION APPLIED TO A MANUFACTURING EXPANSION PROBLEM AREA

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Abstract

This study uses computer simulation to arrive at a specific answer to a critical problem area in a capital intensive manufacturing environment. A Casting Plant is being expanded due to growth in business. The logistics of the operation are such that an existing service facility, an overhead crane, will have added to its present workload, servicing an additional Casting Unit.

Management desired to know what magnitude of crane delays would result from increased task interference as a result of the increased workload on the crane. The answer to this question is crucial since certain types of crane delays generate a loss in casting capacity.

The simulation covers thirty-seven discrete types of tasks that the crane is required to do. These tasks are classified into three general types -

1) Fixed Time of Occurrence
2) Random Time of Occurrence
3) Random Time of Occurrence within some fixed distribution of known cycle times.

The simulation is designed to simulate operations for one-month, using one-minute time units.

INTRODUCTION

The manufacturing environment provides an extremely challenging area for applications of simulation. Many manufacturing problems become so involved and complex, that a tool like simulation is often a necessity to meaningfully capture the interrelationships of variables characteristic to the manufacturing environment. These complex interactions and the "real world" type problems of the manufacturing area are precisely the challenge. An additional facet that increases the challenge is dealing with manufacturing personnel in formulating and analyzing a simulator for a given situation. Manufacturing people, from necessity, must deal with a barrage of pressing daily problems and tasks. Therefore, careful project management is required to help insure the maximum utilization of the invaluable input the manufacturing people have to offer.

Through careful design and feedback control, a simulation study may be executed in such a way that the manufacturing people are "on board" the project from its design through its conclusion. The value of this direct involvement cannot be overstated; in addition to better parametic input to formulate the model, the results of the study have a much greater probability of actually becoming utilized input to the decision-making process. This fact results from these people's having a better understanding of, and therefore, more confidence and trust in the technique, as a result of their involvement throughout the development of the project.

The structure of this paper will basically follow the sequence of steps used in executing the project. Technical information is, for the most part, displayed in the appendixes, while the body of the report focuses more on the logistics of successfully executing the simulation study. Project structure is given below:

1. Problem Definition
2. Collection and Development of Model Parameters
3. Formulation of the Model - Present Situation
4. Benchmarking the Model
5. Addition of Proposed Equipment to Model
6. Conclusions and Results
7. Summary

A brief description of the manufacturing operation is given in APPENDIX C to aid in understanding the nature of the problem at hand.

PROBLEM DEFINITION

As a result of the business growth and predicted future growth, manufacturing capacity of the Casting Plant was projected to become insufficient to meet market demand. This projection signaled management that the casting operation had to be expanded.

Although the original design of the existing casting plant incorporated future expansion capabilities in casting equipment, it did not inherently provide for expansion of peripheral service equipment. One critical consideration in this area was concerned with overhead crane workload capacity. The present overhead crane was believed to be operating at a level near its capacity in the present layout.

Workload on the crane is critical to the casting plant operation. Certain types of crane delays occur as a result of crane task interference (more than one task requiring service simultaneously). These delays often cause an extension of the casting cycle and subsequently a loss in total casting capacity. With an estimated 20-25 per cent increase in crane workload projected as a result of the additional casting equipment being planned, a significant question began to crystalize. This question became a statement of the problem this simulation study would be called upon to solve.

<u>How much casting capacity would be lost, without modification to the overhead crane operating system, as a result of the new casting equipment being brought on line?</u> The answer to this question was the absolute objective of this study.

Several sub-questions required answers to help answer the major question and to provide other decision-making information to manufacturing management.

1. What magnitude of crane task interference would occur?
2. What new workload would result for the crane?
3. Would interference be great enough to justify extensive research to alleviate same?
4. Was it possible that no real problem existed?

After some analysis by manufacturing management, it became evident that the crane operating system was extremely complex and almost impossible to reliably analyze by conventional methods. Assistance in analyzing the situation was requested by manufacturing management, and it was specifically requested that a simulation model of the crane operating system be constructed.

The fact that manufacturing had specifically requested the simulation study proved to be extremely valuable throughout the study. This fact helped elicit good cooperation from the manufacturing operating personnel from the design phases to the conclusion of the project. This involvement of manufacturing personnel at all phases of the study served to inform them about the technique of simulation and, in turn, generated, in them, a trust in the method and its results, probably unattainable by any other method. In short, the results of the study were viewed as reliable inputs to the decision-making process by manufacturing.

Reiterating, the objective of the simulation became to measure the magnitude of the expected casting capacity loss due to the increased workload of the overhead crane. Given this measure, manufacturing would be in a position to make a more intelligient and well-informed decision as to what course of action should be taken.

DEVELOPMENT OF MODEL PARAMETERS

Manufacturing involvement in this phase of the project was critical. In essence, they would describe the system and their description would be abstracted into a simulation model. It is important to note that a model was not constructed and submitted for manufacturing approval; the model was developed with manufacturing an integral part of the development.

A series of meetings were held with operating and management personnel ranging from first line supervision through Director of Manufacturing. The initial meeting was somewhat unstructured. Generalities about the project were explained, and "rough" descriptions of system parameters were developed. At subsequent meetings, parameters were refined and expanded until all parametric information was developed.

Development of parameters consisted of accumulating information such as descriptions, detailed times for executing tasks, and descriptive information relative to distribution of occurrences of the various tasks.

Each crane task (16 discrete types) was detailed by sub-dividing it into sub-tasks. (See APPENDIX A) For example, one task might be broken down into 5 sub-tasks; each sub-task with a specified time for completion. Tasks were detailed in this manner in order that task priorities might be handled in the most realistic manner possible. Task breakdown and task priorities are discussed further in the FORMULATION section of this paper.

After several meetings with manufacturing, a sufficiently complete set of crane activities and their descriptions were compiled. At this point, a study of several months' past production and maintenance history was done, using the information previously developed as a basic structure for gathering the data. For example, given the various tasks, the study was used to develop occurrence frequencies for the tasks, based on history.

The results of the historical study were combined with manufacturing's best "operating feel" to yield the best estimate of the system parameters involved in this simulation. Specifically at this point, all crane tasks were identified and defined, frequency distributions for occurrences for each type task were complete, the nature of the occurrence distribution was known, and priorities had been assigned to the tasks.

FORMULATION OF THE MODEL - PRESENT SITUATION

Formulation of the model combined the parametric information that had been previously developed with the necessary logic to properly represent the interactions of the various components of the model.

A major part of the program logic required was knowledge about logical sequence of occurrence. That is, what events could logically occur at the same time and which events must occur at mutually exclusive times. Through cooperation with operating personnel, a matrix was developed that fixed which events could not happen simultaneously. (SEE APPENDIX B)

The other major part of logic development used in the model, dealt with generating tasks by the proper distributions. During this phase, it became clear that the crane tasks that had been defined could be classified into three types with respect to the nature of the occurrence distributions. These classifications were:

1. Totally random occurrences.
2. Totally random occurrences within some known but varying cycle time.
3. Fixed time occurrences.

The simulation program was developed or structured into three main sections that correspond to the three occurrence types.

A specific example of each occurrence type might be helpful.

The totally random events are exactly what the name implies. There is a known fixed number of occurrences of this type event, but the time of an occurrence is generated in a truly random way. For example, furnace failures are considered to be totally random. Their occurrences are equally likely at any logical time throughout the simulation.

An example of an event that is random within a known cycle time is removing cast bars from the casting equipment. Occurrence time for this task is assigned by a random distribution given a cycle time assigned by a known distribution.

A unit change on a casting unit is an example of a fixed time occurrence. The time for this task to occur was assigned before the simulation and its occurrence was forced to concur with this assignment.

It is worthy to note that the fixed occurrence tasks are in reality not fixed. They are referred to as fixed here, because they were dealt with in the actual simulation program as though they were fixed. These "fixed" occurrence times were preassigned by psuedo random generation. They were handled as "fixed" in the model to assure logical execution sequences.

As mentioned briefly before, each of the sixteen crane tasks were sub-divided by breakpoints into sub-tasks. This was done to facilitate the most realistic application of job practices.

Since many of the crane tasks are relatively long in duration and consist of several distinct steps, it was decided to allow the crane to be pre-empted at any breakpoint in a major task if a higher priority task was waiting. The pre-empted task or tasks would be completed as priorities and crane workload allowed. In this manner, the model operated the crane very much as it was physically operated. Queue statistics on all task and task breakpoints were tabulated for analysis.

The model was designed to simulate a month's activity. The smallest time unit used in the model was one minute. All time statistics were accumulative in terms of minutes.

An advantage capitalized on in this study was that initially, the simulation model simulated an existing set-up. Given the vast knowledge the manufacturing personnel had gained by experience, it was possible to calibrate or benchmark the accuracy of the model before adding the unknown element, the additional equipment. In this way, the manufacturing people gained additional confidence in the model, since they could see that it was simulating the existing operation with a high degree of accuracy.

BENCHMARKING THE MODEL

This phase proved to contribute more than any other to management's confidence in the simulation model and more importantly, the acceptance of its results.

Several simulation runs were made of the "before" situation. The results were tabulated for management review. Due to the structure of the model, it was possible to determine many significant operating parameters that could be measured against reality or known past performance. For example, it was possible to report production for the month, not only in total, but in some detail with respect to product mix. The fact that production generated by the model was totally believable, when compared to actual history, played a major role in convincing management that the model was valid. It was also possible to demonstrate that all prescribed tasks had been completed by the crane throughout the month. Again, task occurrences closely paralleled actual experience. (See APPENDIX D)

Given the confidence gained in the model by "benchmarking" it with reality, the additional equipment was added to the model for evaluation.

Needless to say, the model was designed so that the additional equipment could be easily incorporated. The author's intention and approach from the beginning was to model the present situation, gain the confidence of management by demonstrating the model's accuracy, and insert new equipment and measure its effect. This approach was taken to maximize the probability of acceptance of the studies results. The method proved to be a good approach.

ADDITION OF PROPOSED EQUIPMENT TO MODEL

The equipment that was projected to be added to the casting operation was incorporated into the existing and accepted model of the present casting operation.

Simulation runs were made with the revised model. By comparing the "before" and "after" simulation run results, it was possible to achieve the project objectives.

The confidence that had been gained in the model by this time really paid off throughout the remainder of the project.

The comparisons of before-and-after run results allowed predictions to be made on the critical characteristics of the crane operating system. Specifically, it enabled the estimation of increased casting delay due to crane task interference increases.

CONCLUSIONS AND RESULTS

Conclusions were drawn by comparing the simulation of the present casting operation, an accepted valid picture of reality, to the simulation results of the proposed casting operation with the additional equipment.

The major conclusion drawn showed that due to increased crane task interference, a 2.8% loss in capacity could be expected. This percentage was, in turn, converted into total pounds of production loss to be expected. This fact then became the major contribution of the simulation to the decision process. The magnitude of the problem had been quantified and it was now up to management to determine what action was required.

The important contribution this study made was that management was in a position to make a much more informed decision that it would have been without the simulation. Critical to this fact was that management accepted the results of the simulation as valid.

Due to the proprietary nature of many of the statistics involved, relative changes between present and proposed operations are shown; no absolute statistics are given.

Realizing the detailed structure of the model, it is possible to conclude that the difference measured between the two situations are attributable strictly to the increase in crane task interference. The following table shows some critical relative statistics between the two situations simulated.

COMPARATIVE STATISTICS BETWEEN PRESENT AND PROPOSED SITUATIONS SIMULATIONS

	PROPOSED SITUATION
Average Number of Casting Cycles Per Day Per Machine	2.8 % Decrease
Crane Workload	15 % Increase
Zero Wait Time Bar Removals	17 % Decrease
Average Wait Time For All Bar Removals	44 % Increase
Average Wait Time for Bar Removals That Had To Wait	No Change
Percent of Bar Removals When More Than One Production Unit Was Ready To Have Bars Pulled At The Same Time	7.9 % Increase
Percent of Occurrence of Bar Removals That Exceeded Allowable Delay	4 % Increase

SUMMARY

If this summary had to be limited to two words, those two words would be MANAGEMENT INVOLVEMENT.

Any competent O.R. oriented person can develop a simulation model of a situation. This fact alone, however, means very little. Unless the simulation gains management's confidence and acceptance, the study is worthless to the organization.

It is possible to greatly enhance the probability of management acceptance of a simulation if management involvement and participation in the simulation are forced to a maximum.

This involvement should spread over all levels of management involved and should be sustained throughout the study.

The final acceptance and utilization of a simulation study are less related to the technical excellence of the study than they are to the confidence it is possible to gain from management if the project is executed properly. This statement is not intended to say that technical excellence is not a requirement for ultimate success, but to stress that management participation cannot be overlooked or underestimated if simulation's full potential is ever to be realized.

APPENDIX A

DETAILED DESCRIPTIONS

TASK	DESCRIPTION	BREAKPOINT TIMES * (MINUTES)	PRIORITY
D. C. Casting Bar Removal	Cast bars must be removed from casting units and moves to other equipment.	11 (No Breakpoints)	10 (Top)
Coil Change	As a result of failure, heating coils must be replaced.	10-5-20-40-20-5-10	9
Replace Charge Weigh Line	During charge weigh line failure, crane must move materials to casting floor ordinarily done by charge weigh line.	6	8
Replace Gantry Crane	During gantry failure, crane must handle gantry crane's jobs on the casting floor.	6	8
D.C. Mold Carriage Change	Replacing the mold carriage on D.C. Casting units.	6-6-6-6	7
D.C. Mold Liner Change	Replacing the mold liners on D.C. Casting units.	5-5	7
D.C. Unit Change	Completely changing 5 melt furnaces and holding furnace associated with D.C. Casting	145-10-10-10-10-10-10-10-10-60-10-10-10-10-120-6-6-6-6-10-10-10-10-120-20-15-30	6
Unplanned Melt Changes	Changing only 1 of the 5 melt furnaces on a casting unit as the result of some failure.	10-5-10-40-10-15-20	6
5-Melt Change	Replacing the 5 melt furnaces assocated with	10-5-10-40-10 Then 13-10 5 Times 5 Times	6

DETAILED DESCRIPTIONS

TASK	DESCRIPTION	BREAKPOINT TIMES * (MINUTES)	PRIORITY
Random Tasks	Small jobs such as moving materials to casting floor.	5	5
Ascast Bar Removal	Removing bars from another type of casting unit.	5	5
Booked Mold Casting Mold Changes	Replacement of molds on "book mold" casting unit.	20-25	4
Ascast Mold Change	Replacement of molds on "ascast" casting unit.	6-6	4
Ascast Furnace Change	Replacement of melting furnace on ascast unit.	15-15-10-10-10	4
Changing Wertli	Molten metal must be carried to this production unit by the crane.	10	4
Wertli Failures	Given certain types of failures on this production unit, the overhead crane is required to help recover the unit.	10-20-10	4

* Underlined times are times crane is required. Times not underlined must elapse before the next step is done, however, the crane is free to do another job during the non-underlined times.

APPENDIX B

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. D.C. Bar Removal	X	X			X	X	X		X							
2. Coil Change	X	X					X	X	X							
3. Charge/Weigh Failure			X													
4. Gantry Failure				X												
5. D.C. Mold Carriage	X				X		X									
6. D.C. Mold Liner	X					X	X	X								

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
7. D.C. Unit Change	X	X			X	X	X	X								
8. Unplanned Melt Chg.		X				X	X	X	X							
9. 5-Melt Change	X	X						X	X							
10. Random Task										X						
11. Ascast Bar Removal											X		X	X		
12. Book Mold Mold Chg.												X				
13. Ascast Mold Chg.											X		X			
14. Ascast Fce. Chg.											X			X		
15. Charge Wertli															X	X
16. Wertli Failure															X	X

Note: X Indicates Row Event and Column Event May Not Occur Simultaneously.

APPENDIX C

DESCRIPTION OF MANUFACTURING OPERATION

This is a large manufacturing business producing copper and copper-base alloy strip. Specifically of interest here is the casting operation.

The casting operation employs a semi-continuous direct-chill casting process. The function of the casting operation is to provide large cast bars of non-ferrous alloys for further processing by rolling mills and fabricators. The bars are cast from various combinations of virgin and scrap raw materials.

The casting operation consists of a number of sub-systems which include melting furnaces, holding furnaces, casting pits, and various supporting material handling equipment. Perhaps the most critical piece of material handling equipment is the overhead cranes which has the ability to move the entire length of the casting plant. The crane tasks are described in detail in APPENDIX A.

The crane has serviced the operation in a totally adequate manner to-date. Now, with plans to add casting equipment, the question arises as to whether the crane will be able to handle the subsequent increase in crane tasks.

APPENDIX D

COMPARISON OF HISTORICAL AND SIMULATED TASK FREQUENCIES

	% ERROR IN SIMULATED FREQUENCY
1. D.C. Bar Removal	Not Applicable
2. Coil Changes	0%
3. Charge/Weigh Failures	30%
4. Gantry Failures	30%

COMPARISON OF HISTORICAL AND SIMULATED TASK FREQUENCIES

	% ERROR IN SIMULATED FREQUENCY
5. D.C. Mold Carriage Change	0%
6. D.C. Mold Liner Change	0%
7. D.C. Unit Change	0%
8. Unplanned Furnance Changes	40%
9. 5-Melt Changes	0%
10. Random Tasks	4%
11. Ascast Bar Removal	20%
12. Book Mold Mold Changes	0%
13. Ascast Mold Change	0%
14. Ascast Furnace Changes	0%
15. Charging Wertli	20%
16. Wertli Failures	10%

APPENDIX E

PROGRAMMING CONSIDERATIONS

The simulation model was written using RCA's Flow Simulator language. Flow Simulator is a language very similar to G.P.S.S. and was selected basically because the computer available was a RCA Spectre 70 on which the simulation language available was Flow Simulator.

The programming problem most basic to the success of the project was, of course, representing the crane operating system in the most realistic manner possible. To achieve this goal, certain types of activities were fixed in time prior to the simulation run. This pre-assignment was done using a combination of randomness and logical pattern knowledge for events occurrences.

In the simulation program, these pre-assigned tasks were handled as follows: A function was set for each day to be simulated which contained code for the proper pre-assigned tasks to take place on that day. These functions, in conjunction with the various generate statements, kept transactions coming at the crane in a logical pattern throughout the simulation.

Both tasks associated with pre-assigned events and random events contained breakpoints as explained in the body of this report. These breakpoints allowed the crane to be pre-empted within a job, if a higher priority task came due. The task time distribution associated with the various tasks were handled by creating a function for each task which included advance times for service and free time for the crane within a job execution.

For example, a job could consist of the following -

5 Minutes	Crane Time
6 Minutes	Crane Time
10 Minutes	Non-Crane Time
7 Minutes	Crane Time

During the 10-minute non-crane time, the crane was considered to be free for executing other tasks.

Various tables were set up to collect data in addition to the standard data output of Flow Simulator. For example, a table was generated for assigned cycle times and for realized cycle times. Comparing those two distributions was helpful in demonstrating the effect of workload on casting cycle time realization.

Tables were also kept showing interference patterns. These tables indicated what tasks were interferring with what other tasks. This information was collected to help in designing new procedures for the actual crane operating system to minimize interference in the future design.

The smallest unit of time considered in the simulation was one minute; the total simulated time period was one month. The simulation took approximately 25 minutes to simulate one month and required 220K of core.