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A SIMULATION STUDY OF AN AUTOMOTIVE FOUNDRY PLANT MANUFACTURING ENGINE BLOCKS

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ABSTRACT

This paper discusses the initial efforts to implement simulation modeling as a visual management and analysis tool at an automotive foundry plant manufacturing engine blocks. The foundry process was modeled using Pro Model to identify bottlenecks and evaluate machine performance, cycle times and production data (total parts, rejects, throughput, products/hr) essential for efficient production control. Results from the current system identified assembly machine work area as the bottleneck (although utilization was greater than 95% for two assembly machines) resulting in high work-in-process (WIP) inventory level, low resource and machine utilization. Based on these results, optimum numbers were identified through use of scenarios by varying the number of assembly machines and processing time of each machine. In addition to these scenarios, strategies for production control involving buffer sizes were also made.

1 INTRODUCTION

Survival of any industry in today's competitive market place depends on response time, production cost and flexibility in manufacturing (Chase et al. 2001). Automotive foundries are no exception to this rule. Hence strategies to increase throughput while reducing production costs are being implemented. One efficient strategy to reduce production costs is by better control of the manufacturing process. But control of the process is possible only if the intricate details of the system are known. Computer simulation of the casting process offers a cost-effective solution not only to visualize the processes but also enables us to identify bottlenecks in the system.

The automotive foundry plant located in the Midwest uses the lost foam casting process to manufacture engine blocks using a complex process involving various resources (e.g., molding machines, assembly machines, robots, operators, etc.) and manufacturing procedures. Interactions and interdependencies between the activities makes it difficult to monitor the processes and necessitates extra effort to analyze equipment/operator efficiency. Thus, for effective production control, identification of machine performance, cycle times and production data (total parts, rejects, throughput, products/hr) becomes critical.

It was identified that this foundry process required a long lead-time (due to the nature of process and downtime) and a lot of manual material handlings (e.g., hanging parts on the rack and pushing carts). The scrap rate, particularly the white side (foam), was considerably high. It was also considered that the work-in-process (WIP) inventory level was significantly high. The production supervisors had to spend a significant amount of time to collect data from the shopfloor including hourly production counts, percent uptime, and downtime reasons. Management (e.g., plant manager, production manager and engineering manger) had a hard time achieving visual management in terms of real time monitoring and control of the foundry process.

The objective of this project was to simulate the foundry process for manufacturing engine blocks and evaluate effectiveness of the process in terms of machine and system performance. Particularly, inventory reduction and production control will be focused in the simulation. To implement the simulation structure, cycle time, total parts, and rejection rate were used. Results from the simulation can provide valuable information and alternative options to the management (e.g., plant manager, production manager and engineering manger) in order to improve the plant layouts, machine utilization, inventory control, total manufacturing cost reduction, etc. Thus, the simulation could assist the production/operation managers and plant manager to identified problems and select a best solution. Subsequently strategies for better plant maintenance and control can be initiated.

2 SYSTEM DESCRIPTION

The foundry process begins with molding beads (Styrofoam) to each slice A, B, C, D, and G/S (Gate/Sprue). Each molded slice is loaded in an empty cart and then transported to the aging area. After slices are matured for at least 3 hours, the aged slices are passed to assembly machines 1 (slices A/B) and 2 (slices C/D), respectively. The assembled slices (cluster) with G/S are then conveyed to the coating area.

The coated clusters (blocks) in a rack are transferred to the dry oven. The dry oven forwards every 10 minutes and a rack stays in the dry oven 2 hours to complete one cycle. The dried blocks are then transferred to the casting area. After the aluminum cast, the blocks are then conveyed through the off load conveyer to the pin marker. Then, the cast blocks are passed through the saw, the blast, and the off load. Finally, the finished products are transferred to the inspection area equipped with an advanced quality inspection system. In terms of quality assurance, the clusters should be cast within 72 hrs after molding process. The process flow and layout has been detailed in Figure 1.

3 SIMULATION MODELING TOOL

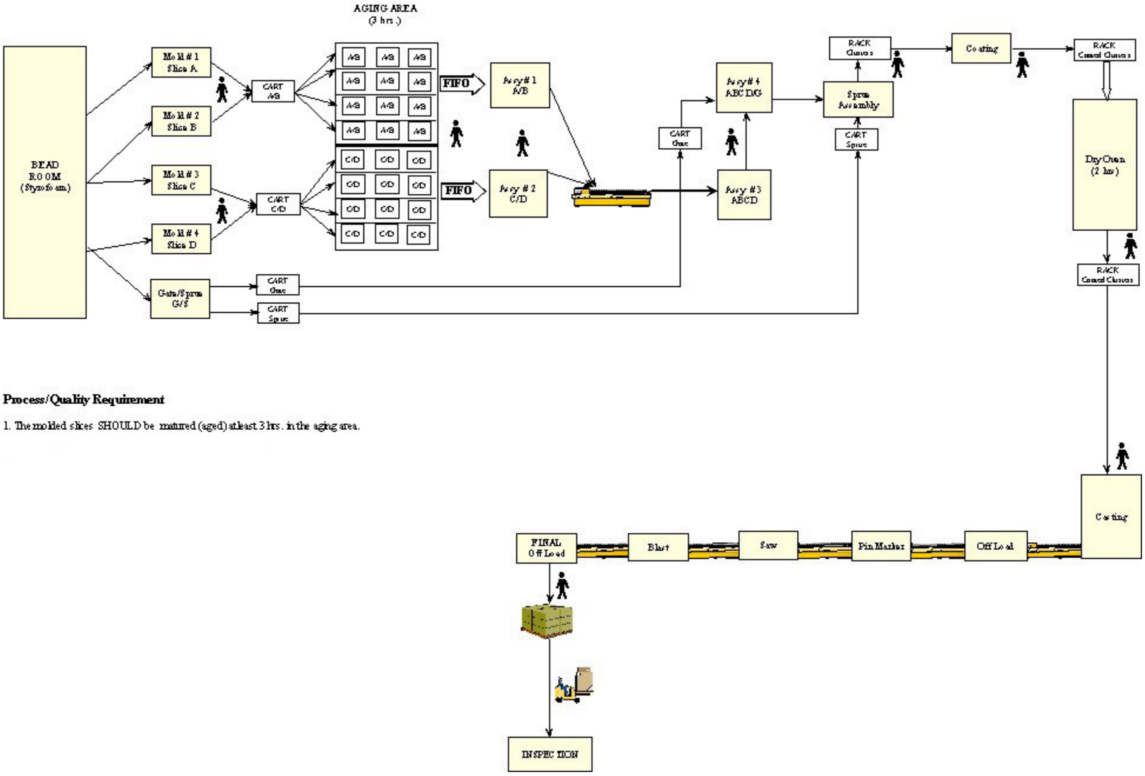
The model of the automotive foundry manufacturing engine blocks was built using the simulation program ProModel (2000). ProModel is a powerful yet easy-to-use pc-based simulation tool for modeling all types of manufacturing systems ranging from small job shops and machining cells to large mass production and flexible manufacturing systems (Harrell and Tumay 1990). ProModel provides a visual representation of the various physical components of the systems and links them through routing and processing statements. ProModel also includes more than 20 statistical distribution types with an additional feature of direct import of data sets.

4 SIMULATION MODEL

In the first phase, a detailed process layout was developed from which entities, location, resources, path network for resources and processes were identified. The next step included incorporation of logic for entity flows through locations including processing time (dealt in detail in Section 5) and the graphics.

Several assumptions were made while developing the model since a tradeoff has to be made between complexity and realism. Accuracy of output of the model was considered when the assumptions were made. The assumptions are listed below:

- Beads are replenished immediately if level falls below a pre-designated level.



Process/Quality Requirement

1. The molded slices SHOULD be matured (aged) at least 3 hrs. in the aging area.

Figure 1: Process Flow Chart of the Automotive Foundry Manufacturing Engine Blocks

- Resources (workers) do not leave the production floor while processing progresses.
- Machines do not break down during this period. (Sufficient data was not available to accurately model the breakdown times).

In the second phase, warm up time and run length were determined. Warm up time determination ensures that data collection proceeds only after steady state of the system is achieved. In a steady-state condition, the response variables in the system (e.g., mean waiting time, throughput rate) exhibit statistical regularity that is the distribution of a response variable is approximately the same from one time period to next. Therefore, the following procedure was employed to determine warm-up period for the foundry simulation.

- Run a preliminary simulation of the system, five replications, average the output values at each time step across replications.
- Observed at what time the system reaches statistically stability.

With the consideration of above statements, the warm-up period in this foundry simulation was set up as 4 hours (i.e., 7:00 a.m. to 1:00 p.m.) from the beginning of shift on Monday. It was expected that the warm-up period provided sufficient time for the steady-state of production processes in the foundry system.

Run length determination was deemed essential since the foundry simulation is a non-terminating simulation and running extremely long simulation is impractical. Since primary focus is on estimating the steady-state parameters, it is usually a good idea to run the simulation long enough, passing warm-up period. Therefore, the run length was determined as 2 weeks, satisfying the constraints including a long enough of simulation length as well as a representative sample of the steady-state length of the system.

In the third phase, the working model was verified and validated to investigate whether the developed foundry simulation model correctly reflects the conceptual model. Model verification and validation were considered to be critical procedures to assess success of this simulation project. While simulation was running, the events occurring in the model was noted using the trace function provided in ProModel. The following processes were used for the model verification/validation.

- Tracking the routes and flow/process of individual entity in the system.
- Tracking the routes and networks of individual resource in the simulation.
- Studying the production number in each machine as well as throughput number.
- Verifying the number of rejected/scrape parts with the rejection criteria/logics.
- Running the simulation a sufficient period of time to check accountability/credibility of the simulation model.
- Verifying the layouts including the locations of machines and resources.

5 DATA COLLECTION

One of the criteria to program foundry simulation using ProModel was to define the distribution of process time/waiting time in each process of the foundry. Thus, the collected process time of molding machines, assembly machines, coating, dry oven, casting, off load, pin marker, saw, blast, and final off load were studied to generate the best fitted distribution. Two main steps were conducted to test collected data. The first step tested for independence of the collected data. Scatter plot method were employed for the data collected on molding machine 1, 2, 3, 4, and 5; assembly machine 1, 2, 3, and 4; coating; dry oven; casting; off load; pin marker; saw; blast; and final off load. A total of 30 observed processing times (minutes) for each machine/process were plotted, respectively to test whether the value of one observation is not influenced by the value of another observation. No specific trends/patterns were observed in the individual plots indicating that the observations are independent.

The second step included the fit distribution tests for which Crystal Ball software plugged into Microsoft Excel was utilized. The procedures of the fit distribution test and output screens (comparison charts) are listed below:

- Distribution Gallery
- Fit Distribution
    - Crystal Ball will fit a probability distribution to the selected data (i.e., select data range)
    - Fit to all continuous distribution
    - Ranking method used Chi-Square Test
    - Selected comparison charts and Goodness-of Fit statistics

The summary of the ranked fitted distribution using Chi-Square test for the process time in each molding machine 1, 2, 3, 4, and 5; assembly machine 1, 2, 3, and 4; coating; dry oven; casting; off load; pin marker; saw; blast; and final off load, respectively can be found in tables 1 through 4.

6 SCENARIOS

Work in process (WIP) and processing times were the main concerns in the foundry, hence, with this mind, four scenarios including existing scenario were created wherein number of assembly machines and processing times of

Table 1: Summary of the Ranked Fitted Distribution using Chi-Square Test for the Process Time in Molding Machines 1, 2, 3, 4, and 5

	Mold Machine 1		**Mold Machine 2**		**Mold Machine 3**		**Mold Machine 4**		**Mold Machine 5**	
Ranking	**Distribution**	**p-value**	**Distribution**	**p-value**	**Distribution**	**p-value**	**Distribution**	**p-value**	**Distribution**	**p-value**
1	***Lognormal***	***0.849***	***Lognormal***	***0.94***	***Weibull***	***0.549***	***Lognormal***	***0.753***	***Lognormal***	***0.659***
2	Normal	0.849	Normal	0.849	Beta	0.368	Normal	0.659	*Normal*	0.494
3	Logistic	0.753	Logistic	0.849	Logistic	0.362	Logistic	0.659	*Logistic*	0.423
4	Triangular	0.67	Triangular	0.819	Normal	0.221	Beta	0.549	*Weibull*	0.368
5	Beta	0.67	Beta	0.819	Triangular	0.074	Weibull	0.449	*Beta*	0.301
6	Weibull	0.449	Weibull	0.67	Gamma	0.01	Gamma	0.449	*Gamma*	0.301
7	Gamma	0.247	Gamma	0.67	Uniform	0.006	Triangular	0.301	*Triangular*	0.05
8	Uniform	0.094	Uniform	0.362	Lognormal	0.004	Uniform	0.027	*Uniform*	0.027

Table 2: Summary of the Ranked Fitted Distribution using Chi-Square Test for the Process Time in Assembly Machines 1, 2, 3, and 4

	Assembly Machine 1		**Assembly Machine 2**		**Assembly Machine 3**		**Assembly Machine 4**	
Ranking	**Distribution**	**p-value**	**Distribution**	**p-value**	**Distribution**	**p-value**	**Distribution**	**p-value**
1	***Gamma***	***0.0743***	***Lognormal***	***0.572***	***Normal***	***0.659***	***Triangular***	***0.165***
2	Lognormal	0.0051	Beta	0.247	Weibull	0.449	Weibull	0.091
3	Weibull	0.0030	Gamma	0.202	Beta	0.449	Gamma	0.074
4	Triangular	0.0020	Weibull	0.111	Lognormal	0.362	Normal	0.066
5	Normal	0.0002	Triangular	0.111	Gamma	0.301	Beta	0.027
6	Uniform	0.0000	Normal	0.094	Triangular	0.135	Lognormal	0.022
7	Beta	0.0000	Uniform	0.079	Uniform	0.003	Uniform	0.003
8	Exponential	0.0000	Exponential	0.000	Exponential	0.000	Exponential	0.000

Table 3: Summary of the Ranked Fitted Distribution using Chi-Square Test for the Process Time in Coating, Dry Oven, Casting, and Off Load

	Coating		**Dry Oven**		**Casting**		**Off Load**	
Ranking	**Distribution**	**p-value**	**Distribution**	**p-value**	**Distribution**	**p-value**	**Distribution**	**p-value**
1	***Gamma***	***0.549***	***Normal***	***0.3080***	***Gamma***	***0.819***	***Triangular***	***0.549***
2	Weibull	0.247	Uniform	0.1577	Weibull	0.819	Lognormal	0.261
3	Normal	0.187	Triangular	0.1353	Lognormal	0.753	Gamma	0.247
4	Lognormal	0.158	Beta	0.1353	Normal	0.423	Normal	0.221
5	Beta	0.091	Lognormal	0.1328	Logistic	0.423	Logistic	0.221
6	Triangular	0.018	Logistic	0.1328	Triangular	0.368	Weibull	0.111
7	Uniform	0.013	Weibull	0.0608	Beta	0.368	Beta	0.111
8	Logistic	0.013	Gamma	0.0608	Uniform	0.187	Uniform	0.027

Table 4: Summary of the Ranked Fitted Distribution using Chi-Square Test for the Process Time in Pin Marker, Saw, Blast, and Final Off Load

	Pin Marker		**Saw**		**Blast**		**Final Off Load**	
Ranking	**Distribution**	**p-value**	**Distribution**	**p-value**	**Distribution**	**p-value**	**Distribution**	**p-value**
1	***Lognormal***	***0.572***	***Lognormal***	***0.753***	***Beta***	***0.449***	***Lognormal***	***0.362***
2	Triangular	0.368	Normal	0.753	Triangular	0.449	Gamma	0.247
3	Normal	0.158	Beta	0.549	Logistic	0.261	Normal	0.221
4	Logistic	0.158	Logistic	0.423	Uniform	0.094	Logistic	0.133
5	Weibull	0.074	Triangular	0.368	Lognormal	0.046	Triangular	0.111
6	Beta	0.074	Weibull	0.247	Normal	0.032	Beta	0.111
7	Gamma	0.074	Gamma	0.091	Weibull	0.018	Uniform	0.066
8	Uniform	0.011	Uniform	0.002	Gamma	0.018	Weibull	0.033

these machines were varied. A scenario was created by increasing the number of assembly machines while the rest of the scenarios dealt with increase or decrease of processing times of Assembly1_ AB, Assembly2_ CD, Assembly3_ ABCD and Assembly4_ ABCDG. Assembly machines AB and CD were observed to be the bottleneck in the system hence scenarios were mainly developed for these machines whereas Assembly3_ ABCD and Assembly4_ ABCDG are machines which are mainly dependent on processing of the slices AB and CD, and slice ABCD respectively.

7 ANALYSIS OF RESULTS

7.1 Analysis of Current System

A single simulation run for 2 weeks (includes a warm up period of 6 hrs) on the current system yielded several important results. WIP in the process was observed to be high (average 310 units). But this can be attributed to dependency of processes on assembly machines AB and CD and use of buffers storage which contributes significantly to the WIP.

Assembly AB and Assembly CD exhibited high utilizations (95% and 99% respectively). The high utilization is attributed to the unit capacity of the two workstations. Hence further investigation were conducted by increasing the number of machines. It is to be noted that breakdown of these machines were not modeled (due to lack of statistical data), hence further investigations are needed to study the effect of machine breakdown on WIP and the system.

Analysis of utilization of the resources showed that unequal work distribution between operators. Idle time for Operator MMH Area (79.50%), Operator Assembly ABCD (56%), Operator Assembly ABCDG (38.63%), Operator Cluster Assembly (95%), Operator Coating (75%), Operator Dry Oven (87%) suggests underutilization of personnel and therefore efforts be made to automate/semi-automate the whole process.

7.2 Comparative Analysis

Comparative analysis of the output from the developed scenarios were used to answer the What-If questions that stemmed from observation of results of current system.

Table 5: Work In Process Per Alternative

Rep.	Scenario 0	Scenario 1	Scenario 2	Scenario 3
1	290	269	292	340
2	296	242	297	231
3	277	293	232	296
4	387	252	276	266
5	300	206	222	284
Avg	**310**	**253**	**264**	**283**
STD	**44**	**32**	**34**	**40**

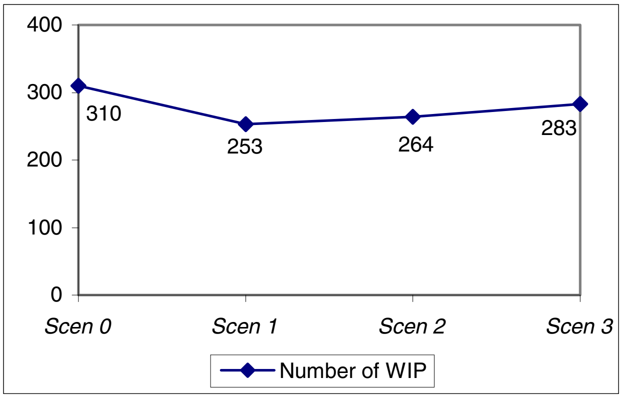


Figure 2: Work In Process Per Alternative

As expected, increasing capacity of assembly area machines (Scenario 1) led to a significant decrease of the number of WIP (i.e., slices) when compared with the existing system (Scenario 0) while reducing the contents in the buffers (see Table 5). It was also noticed that the number of throughput using Scenario 1 was increased compared to that of current system. Because the objectives of this study was to determine how to improve work in process in the foundry, it was evident that based on that measure of performance, alternative 1 was the best option (see Figure 2). Plant redesign efforts can be concentrated on buffer sizes. However, utilization rates of the workers did not improve significantly hence suggesting overstaffing in the plant.

8 CONCLUSIONS AND RECOMMENDATIONS

The results from this study showed that the assembly area, the bottleneck in the system, should be focused for efforts of inventory and production control. It was not desirable to have very high utilization rates in the bottleneck (i.e., Assembly AB and CD) in the queuing system, therefore a sensible alternative would be to increase the number of machines in this area. The alternative selected for the foundry process offered a desirable 23% improvement of the work in process while increasing throughput rates. In addition, the simulation results allowed the foundry's managers (e.g., plant manager and production manager) to target their investment by specifying which investment option offers the highest economic benefits.

Furthermore, utilization rates of the personnel suggested that efforts should be made to semi/automate some of the processes including molding, assembly, and coating processes. A total cost benefit analysis was needed to be conducted to gage the benefits obtained thereby.

Since data for some of the parameters was not available, it was suggested that an extensive study incorporating downtime criteria/logic (e.g., machine break down time) be developed to achieve down time study in order to increase the realism. Finally, a full validation of the simulation is required which can be achieved by comparing actual numbers of throughput and rejected/scrap parts to those from the simulation, using historical records such as throughputs, rejected parts, downtimes, and so on in a long period of time (e.g., months and years).

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