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PERFORMANCE EVALUATION OF AN AUTOMATED MATERIAL HANDLING SYSTEM FOR A MACHINING LINE USING SIMULATION

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ABSTRACT

In the evaluation of a material handling system, multiple factors should be considered, including the plant's facilities, the machinery, the material handling equipment, and of course, the people involved. Simulation techniques can be effectively used in all the phases of this process in order to understand the behavior of manufacturing systems, from the material handling concept definition throughout the system's final implementation. In this paper, an automated material handling system for a cylinder block machining line is proposed and evaluated by means of discrete event simulation using the *ProModel* simulator. Initially, the machining line is modeled with manual material handling to get an estimate of the true line capacity. Then the proposed conveyor system is modeled, and the systems are compared by means of confidence intervals. The results revealed that the automated material handling system causes a slight decrease in the system throughput, while gaining the benefits of a Just in Time based system.

1 INTRODUCTION

The Toluca Engine Plant manufactures L4, L6 and V8 gasoline engines for the local and U.S. markets. The plant currently is in transition from traditional manufacturing to Just in Time manufacturing. The L4 and L6 cylinder block machining line constitutes a great opportunity for continuous improvement methods due to the components' relative importance in the engine. Several actions have been taken to improve the performance of the machining line. Machines were redistributed in U cell layouts, greatly reducing distances and floor space, thus improving general efficiency. However, the material handling equipment in the cells is completely manual and the parts are processed in the workstations without a continuous or logical flow. This results in significant delays in production output, work in process increase, human fatigue, and a general decrease in the productivity of the machining line.

A solution to the problem that focuses on the implementation of a low cost, high efficiency automated material handling system was proposed by a team of workers, engineers and managers. However, the proposal cannot be evaluated by means of theoretical queuing methods due to the complexity of the real manufacturing system and the variables involved. Simulation can in this sense provide a powerful tool for evaluating the performance of a proposed system and choosing the right alternative before actually implementing the solution on the floor (Ramírez 1994). The simulation project undertaken for this purpose was then divided in the following phases:

Phase 1: Analysis of manufacturing process flow dynamics.

Phase 2: Simulation model construction for current and proposed system.

Phase 3: Validation and verification.

Phase 4: Analysis of results.

Phase 5: Conclusions.

2 MANUFACTURING PROCESS

The manufacturing system involved is a rough machining cylinder block manufacturing process that consists of 21 machines and 3 manual operations forming 7 manufacturing cells. The machines are traditional dedicated machines grouped in U shaped cells. This allows the operators (8 in the entire system) to load and unload the workpieces, start the machining cycle, perform minor inspections, and handle the cylinder blocks manually between the operations. The material handling system used consists of standard gravity roller conveyors that follow the layout pattern from the first to the last operation. A layout of the machining line is presented in Figure 1.

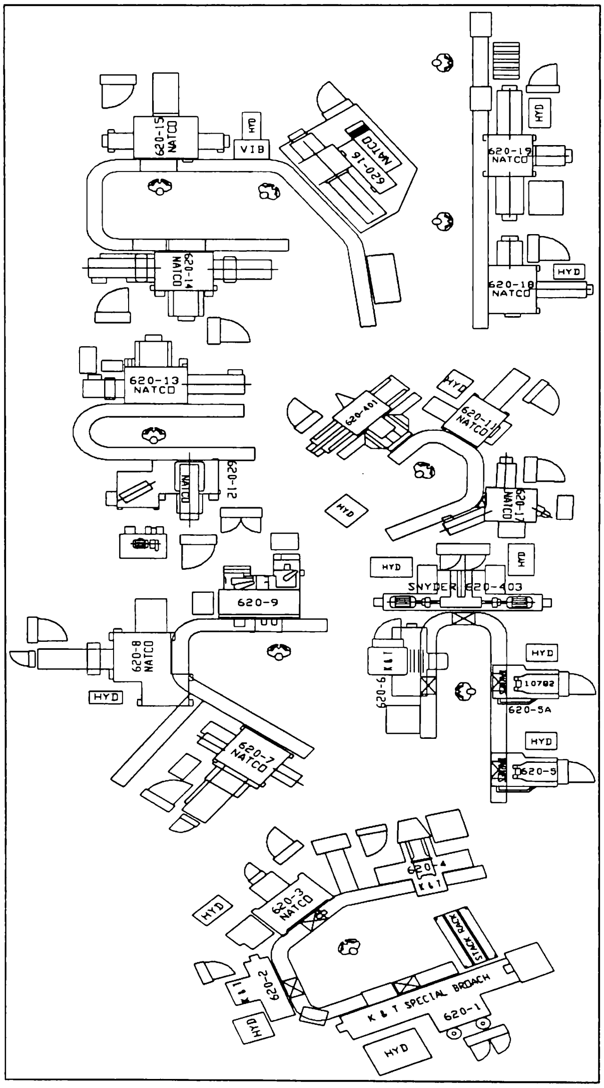

Figure 1: Layout of the Machining Line

The typical operation sequence in a machine with the line full of material is as follows. The operator unloads a cylinder block from the machine, loads the part waiting before the machine, and starts the operation cycle by pushing the required buttons. Then he moves the outgoing part manually to the next operation by pushing it over the roller conveyor and turns the part to change its position if applicable. Finally, he returns to the same machine to repeat another cycle. The operator performs this sequence several times on the same machine until he has accumulated "enough" inventory to go to the next operation. The arrival of raw material castings to the first operation occurs at intervals of 90 minutes by a lift truck delivering a rack with 24 cylinder blocks. The machining line delivers the cylinder blocks to the next department for the finishing operations. The line works one 9 hour shift with a 30 min. break for lunch, 240 days per year. The production plan shows a daily rate of 136 parts to satisfy demand. However, the *true* line capacity has not been established properly since the layout rearrangements.

The multiple functions performed by the operators complicate the operation of the line, not only being responsible of the part processing, but also of the entire material handling for the cylinder blocks. The nature of the 100 lb cast iron workpiece complicates manual material handling, and causes important delays in production output, thus performing non-value-added activities.

3 MATERIAL HANDLING SYSTEM

Analyzing the material flow dynamics, two situations were identified for the material handling in the machining line. A movement identified as *local*, consists of the cylinder blocks transfer in a manufacturing cell from machine to machine. The other movement, identified as *inter-cellular*, consists of the transfer of material from one manufacturing cell to the adjoining cell. The solution proposed for *local movement* consists of the use of motorized roller conveyors instead of the existing gravity conveyors controlled in segments by a PLC. Also, automatic turnover fixtures to change the position of the workpiece were considered. For *inter-cellular* movement, aerial gravity conveyors were designed. These consist of an I beam supported by two structural steel posts. When the operator pushes a button, two small pneumatic pistons are actuated and the workpiece hanging by a hook slides by simple gravity, returning empty in the same manner. Also, an operational method was proposed consistent with JIT principles.

The objectives of the implementation of the proposed material handling system are:

- Maximize the production throughput of the machining line.
- Minimize the cylinder blocks work in process in the system.
- Minimize the throughput time of the parts through the system.
- Maximize the utilization of the material handling system, the machinery, and the workers.

4 MODEL DEVELOPMENT

The simulation project undertaken had the following objectives in order to understand the performance of the proposed material handling system:

- Evaluate the machining line capacity with manual material handling.
- Evaluate the machining line capacity with the implementation of the proposed automated material handling system.
- Evaluate the proposed material handling system performance before its actual implementation.
- Verify the control logic feasibility in order to operate the system JIT.

Initially, the machining line was modeled with the manual material handling system to get a validated model of the real world system and to allow the determination of a line capacity bound estimate not restricted by a specific material handling equipment (Savory, Mackulak, and Cochran 1991). Once validated, this model was modified by substituting the material handling system for the one proposed, obtaining the new line capacity, and comparing with the initial model statistically.

4.1 Data Collection and Model Definition

Time and motion studies performed by the Industrial Engineering Department at the company were the main source for the data required for the simulation models. Other relevant sources were process sheets, maintenance records, scrap and rework records, line layouts and process flow diagrams. Additionally, useful conversations and interviews with line operators, supervisors, manufacturing and industrial engineers and equipment vendors were conducted in order to obtain true and valid data.

Machine downtimes are the most important source of randomness in manufacturing systems. In this study, data were obtained from a maintenance database that contained daily information (throughout one year) on scheduled and non-scheduled downtimes. Only non-scheduled data were collected, considering that preventive maintenance is always scheduled for second or third shifts or weekends. In this way, downtime data were collected for each machine, obtaining also the corresponding up-time figures.

The distribution fitting software *Bestfit* Release 1.02 was then used to perform goodness of fit tests for the mean downtimes and the times between failures. Most of the 21 sets of data for each machine failed to pass the 95% Chi-square test.

The downtimes of 6 machines were fitted by the Pearson V distribution whereas for the remaining data sets continuous empirical distributions were obtained.

The scrap and rework distributions for each machine were modeled considering the mean of the data available. This was assumed considering that this source of randomness is not relevant for the material handling system due to the small relative magnitude of the corresponding data.

4.2 Data Validation

Data collected for building the simulation models were validated against the existing line figures. A structured walkthrough of the conceptual model was also performed to make sure that the assumptions were correct, complete and consistent with the real world system.

4.3 Model Building (Current Situation)

For the model construction, the manufacturing simulator *ProModel for Windows* (ver. 1.10) was selected because of its flexibility in modeling real world manufacturing situations and its user-friendly modeling environment (ProModel Corporation 1993). The package allows an easy model building process in a combined menu-graphic interface. Complex systems, such as the one in this study, can be built easily and debugged very fast. It has good statistical capabilities, and the output reports have a simple format and are easy to interpret. The animation is integrated with the model definition, and the graphic interface can be used at any time to define the systems elements.

The following elements were included in the model definition, as part of *ProModel's* capabilities:

- Entities: There are four types of entities in the model, the rack containing 24 cylinder block castings, the cylinder blocks themselves, scrap cylinder blocks, and rework cylinder blocks.
- Locations: Each of the 21 machines and the 3 manual operations is modeled as locations. The rack where the castings arrive is also a location.
- Resources: There are 9 resources available in the model, 8 machining cell operators and the lift truck that supplies castings to the first operation from the foundry plant.
- Networks: They are made up of the theoretical paths followed by the line operators along the manufacturing cells, and from the foundry plant to the first operation for the lift truck. The path to the cafeteria for the lunch break and back to the line was also modeled. These networks were modeled as bi-

directional, to allow the resources to move to the closest entity at any moment. Location interfaces were also defined to establish the relationship between locations and nodes, for example, for loading and unloading the parts from the machines.

- Processing: The process sheet sequence is modeled here, considering the cycle times for each operation as defined by the time and motion studies available. The scraps and rework are modeled as a percentage. For the material handling system, the operation statement ACCUM is used to model the accumulation of material in the roller conveyor segments between operations and machining cells (31 *local* conveyor segments and 6 *inter-cellular* conveyor segments in the entire machining line).
- Arrivals: The only entity that arrives to the system is the rack with 24 casting cylinder blocks from the foundry plant. This type of arrival has a frequency of 90 minutes, and when arriving to the first operation delivered by the lift truck, the entity splits into 24 individual cylinder blocks ready for processing.
- Variables: Seven are used in the model, two for storing information and gathering statistics, *throughput* and *WIP*, and the rest to simplify the model construction.
- Tables: The machine downtime probability distributions were defined in this module in a tabular way, using a continuous non-accumulated format.
- Shift Assignments: A typical working week is specified here, with days of 9 working hours, from 6:00 till 15:00 with a lunch break from 10:30 till 11:00.
- Layout and Graphics: A layout was constructed graphically resembling the true line configuration, only for validation and modeling purposes. The foundry plant and the cafeteria were also represented graphically.
- Replications: In order to evaluate the performance of both the current and the proposed systems, the following performance measures were established:

- Throughput (pc/time unit)
- Throughput time (time unit/pc)
- Work in process (WIP)
- % in operation for Op. 10, 90 and 220
- % in use for cell operators 1, 3 and 8
- % of utilization for aerial conveyors 1, 3 and 6

The 3 first measures were user defined in *ProModel* for this particular application, and the rest are built-in performance measures available in the software package, as part of its manufacturing oriented capabilities. The *throughput* is computed from the total quantity of finished blocks that exit the system at the end of the replication. The *throughput time* is computed from the average time spent by a block in the entire system, from the first to the last operation. The *work in process* is computed from the average total quantity of blocks in the entire system.

4.4 Verification

Well-known simulation techniques were used to verify the simulation model (Law and Kelton 1991): modular program development, structured walkthrough, output traces, running the model under simplifying assumptions and under a variety of settings of the input parameters, and model animation. *ProModel for Windows* easily allows these tests to performed.

4.5 Validation

The following steps were observed during the validation of the simulation model (Law and Kelton 1991): develop a model with high face validity, test the assumptions of the model empirically, and determine how representative the simulation output data are. This analysis showed that the model output is consistent and correct when compared to the real world system figures.

4.6 Model Building (Proposed Situation)

Once the current situation model was validated, the following modifications were made to represent the proposed system:

- The capacity of the roller conveyors was modified to 1 in the *Locations* module, to allow a one piece flow operation.
- The statement ACCUM was eliminated for the roller conveyor segments in all the processing blocks, thus eliminating material accumulation between operations.
- The 6 roller conveyor segments connecting the manufacturing cells were modified graphically to a line, to represent the gravity aerial conveyors for *inter-cellular* movement.
- The statement USE for the roller conveyors was eliminated in the move blocks in the processing module, to free the operators from the manual material handling.
- The turn of a part to change its traveling and machining position was modified to represent the automatic turnover fixtures, allowing the parts to turn automatically after being unloaded from the previous machine.
- The bi-directional networks in the machining cells operator paths were modified to unidirectional to represent the proposed method of operation. In this one, the operator never repeats an operation and is in constant movement along its cell.

- USE statements for the aerial conveyors were added in the processing module to represent the fact that the operator must load the parts into the hook and press the button to actuate the pneumatic piston to slide the part to the next cell. Also, the next cell operator must unload the part from the hook and press the button to return it to the loading station of the previous cell.

4.7 Verification and Validation

Similar techniques to those used for the current situation model were applied to verify and validate the proposed system. However, the validity of the model is heavily based on the modeler's and system expert's expectations, who believe that the proposed material handling system should outperform the current system. Accumulation was allowed in the roller conveyor segments, observing the proposed operation method. However, after several pilot runs, the system *throughput* incremented marginally but the *work in process* incremented in a sensible way, which is definitely not acceptable. The outputs for the current and proposed simulation models compare mutually in a favorable and congruent way. However, the values for some performance measures show important deviations, which is due to the fact that the proposed system modifies substantially the operation and the capacity of the machining line.

4.8 Design of Experiments

Special care was taken when selecting the initial conditions, so that the performance measures do not depend directly on the system's state at time zero. It was considered that the line is always full of material, even in a model change situation. A warm up period was then necessary to obtain this condition, so that the line can fill from the first to the last operation. The line reaches its average inventory level in the 4th hour of operation for the current system, and in the 2nd hour in the proposed system. In this way a 9 hour warm up period was established, so that all operations have material to process at time zero. During this period, no machine downtimes were modeled, so that the true line conditions start from time zero.

For the purpose of the simulation study, only steady state conditions are of interest. In this way, for both simulation models, a run length of 1 week from 6:00 to 15:00 (Monday till Friday) was established. This was considered acceptable because an important quantity of events occurs in a typical week of operation of the line, so that the statistics gathered can be representative of the system's true performance. In total, 105 simulation hours were scheduled for each model, with 45 effective operation hours.

Initially, 5 replications were performed on each simulation model, obtaining the performance measure with the highest standard deviation value. Considering an arbitrary maximum acceptable error of 10 parts/week between the true and estimated values for the *throughput*, and using the t-distribution with α=0.05 (Harrel et al. 1992), the number of model replications was obtained for each of the current and proposed material handling systems. In this way, applying this criteria, only 5 replications were performed for the current system, and 20 replications for the proposed system, both to obtain a desired accuracy of 95%.

5 ANALYSIS OF RESULTS

Having conducted the previous simulation runs, 95% confidence intervals for the means of the performance measures for both models were obtained directly from *ProModel*, as shown in Table 1.

Table 1: 95% Confidence Intervals for the Selected Performance Measures

PERFORMANCE MEASURE	CURRENT	PROPOSED
Throughput (parts/week)	705 (± 10.4)	687.4 (± 7.2)
Throughput time (sec/part)	252.1 (± 6.8)	268.6 (± 2.7)
WIP (parts)	160 (± 2.6)	32 (± 0.9)
Op. 10 - % operation	19.3 (± 0.7)	18.1 (± 0.1)
Op. 90 - % operation	14.4 (±0.3)	14.1 (±0.1)
Op. 220 - % operation	11.7 (± 0.1)	12.0 (± 0.1)
Operator 1 - % in use	35.5 (± 1.3)	23.4 (± 0.2)
Operator 3 - % in use	30.5 (± 0.7)	19.3 (± 0.2)
Operator 8 - % in use	50.91 (± 0.7)	44.3 (± 0.4)
Aerial A1 - % utilization	90.9 (± 1.9)	37.3 (± 6.3)
Aerial A3 - % utilization	91.4 (± 5.3)	60.4 (± 6.9)
Aerial A6 - % utilization	57.5 (± 4.6)	53.7 (± 5.7)

In order to compare the two systems adequately, two-sample tests were performed for each performance measure. The hypothesis tests show statistical evidence that the following performance measures of the current system are greater than the correspondent measures of the proposed system: *throughput*, *WIP*, *Op. 10 and Op.*

90 % operation, *operator 1, 3 and 8 % in use*, and *aerial A1 and A3 % of utilization*. In the same manner, the tests show that the *throughput time* and the *Op. 220 % operation* of the current system are smaller than the correspondent measures in the proposed system. However, there is no statistical evidence to say that the *aerial A6 % of utilization* of the current system is bigger or smaller than the correspondent measure in the proposed system. In this way, we can make the following conclusions of the performance of the material handling system for the cylinder block machining line.

5.1 Line Capacity

With an important reduction of 80% for the *WIP*, the value of the *throughput* decreases 2.5%, and the *throughput time* increases 6.5%, when using the proposed material handling system, as shown in Figure 2.

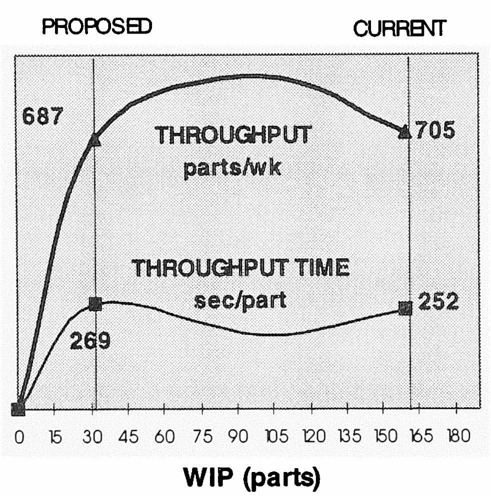

Figure 2: Line Capacity

This behavior is explained if we consider that machine downtimes have a strong influence on the performance of the machining line. When a failure occurs and the machine is down for a period of time during repair, the number of parts before the machine tends to increase, while the number of parts after it tends to decrease. If this condition persists, the parts before the broken machine accumulate and occupy the whole capacity of the conveyors, blocking the previous machines to continue producing parts. In the same manner, if the quantity of parts after the broken machine decreases until the line is empty, the following machines remain idle, unable also to produce parts. These phenomena as a whole makes that a manufacturing system with a small quantity of work in process decreases its throughput rate, in comparison to a system with high levels of work in process. This behavior is well documented with experimental results applied to *transfer lines* (Dallery, David, and Xie 1989).

In order to verify that the throughput rate depends on the work in process level, the proposed model was modified to allow accumulation only in the roller conveyor segments, while preserving the method of operation. The statement ACCUM was then varied from 2 to 7 parts per segment; new simulation runs were performed and the results showed that the corresponding work in process levels were 53, 71, 101, 117, 131 and 147 average parts respectively, as shown in Figures 3 and 4.

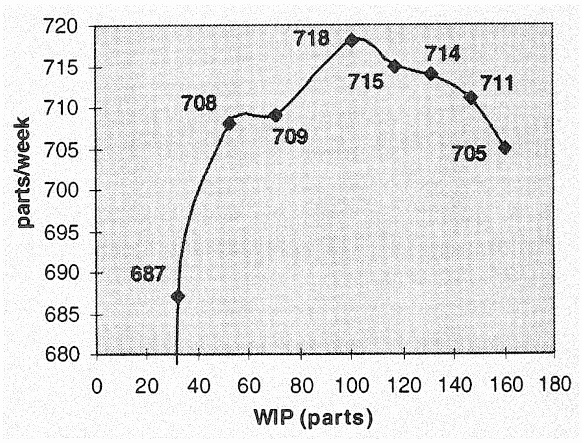

Figure 3: WIP vs. Throughput

As shown in Figure 3, the throughput increases from the case of no accumulation (one piece flow) with 687 parts/week, until a maximum value of 718 parts/week. Then, it descends to the current production rate of 705 parts/week with full accumulation in the conveyors. This is, if we want to maximize the throughput rate, an average work in process level of 101 parts with 4 accumulating parts per roller conveyor segment gives the maximum performance. The opposite behavior occurs with the throughput time, as established by the well-known Little's Law (Baudin 1992), as shown in Figure 4. This time decreases from 268 sec/part for the proposed system until a minimum value of 247 sec/part with an average work in process level of 131 parts with 6 accumulating parts per segment.

Then, the throughput time increases to a value of 252 sec/part, which represents the current operation of the line. Algorithms, such as those in Dallery, David, and

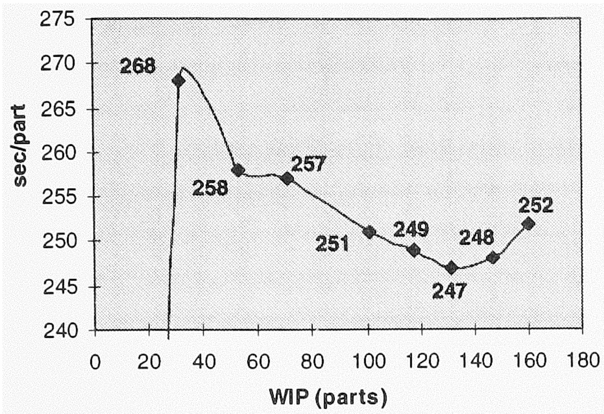

Figure 4: WIP vs. Throughput Time

Xie (1989) and Frein, Commault, and Dallery (1992) can be used to obtain the buffer size between machines for optimizing the throughput rate, but are out of the scope of this study. However, when increasing the accumulating parts between operations, several Just in Time principles are violated, which is not consistent with the previously stated material handling system objectives.

5.2 Machinery Utilization

The machine utilization for the line, measured by the % in operation, decreases slightly for operations 10 and 90 when using the proposed material handling system. This decrease obeys also to the effect of machine downtimes on the work in process behavior, since the throughput rate is strongly related with the equipment utilization. However, it increases slightly for operation 220 when using the proposed system. This is due to the fact that when machine downtimes occur, the parts require more time in the current system to reach the last operation, as effect of accumulation. The opposite occurs in the proposed system, where parts flow rapidly towards the end of the line, as result of the one piece flow operation.

5.3 Work Force Utilization

Results show that worker's utilization suffers a significant reduction, measured by means of line operators 1, 3 and 8, when using the proposed material handling system. The reason for this is that in the proposed system, workers do not perform any more the material handling by themselves, and the corresponding statistic for utilization is not gathered. The only times considered are when the resources (operators) are servicing a location, and when traveling with parts along the machining cells.

5.4 Material Handling Equipment Utilization

Results also show a strong reduction in the material handling equipment utilization when using the proposed material handling system. This is due to the fact that for the proposed system the load capacity is 37 conveyor segments with unit capacity (37 parts). In contrast to the current system, which has the same 37 segments, but with an overall load capacity of 168 parts, an average of 4.5 parts per segment. This over population of production material in the line logically turns into a greater utilization of the material handling devices in contrast to the few parts present in the proposed system.

6 CONCLUSION

Simulation modeling allows engineers and managers to visualize the performance of complex manufacturing system under running changes in the dynamic industrial environment of today.

The simulation study conducted on the proposed material handling system for the cylinder block machining line revealed important information regarding the system performance, as it allowed us to gain valuable experience in implementing the system ahead of time. It also showed that common-sense rules for designing a material handling system do not always work well due to several factors such as actual machine downtimes and work in process level. The slight throughput reduction encountered when using the automated material handling system can therefore be seen as a trade-off for having a more efficient and user friendly line operation.

The simulation model was successfully used to validate the system performance under a Just in Time environment. Also, it assisted in the decision making process for acquiring new material handling equipment for the cylinder block machining line and for other future projects in the company.

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