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SIMULATION OF A FLEXIBLE MANUFACTURING CELL

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ABSTRACT

American aerospace manufacturing operations are evaluating and implementing numerous Flexible Manufacturing Systems. Each application is a complex combination of various support systems found in a more traditional production environment. Predicting how these systems will work within the integrated framework of an FMS can be very complicated. Simulation is a valuable tool for not only evaluating a complex system for feasibility, but it can also be incorporated as a design aid. The following paper describes how a simulation model was used to assist in the design and planning of an FMS.

A SLAM discrete event simulation model provided many insights into proposed system behavior and how it affected performance. In addition, this model functioned as a design tool during system development. Model development centered around a group participation concept. The model provided statistics for machine tool utilizations, manual station utilizations, inventory levels, product lead times, production levels, and queueing requirements.

This particular FMS was dedicated to the machining of a complex product requiring special material handling and quality considerations often associated with high tolerance machining processes. Several simulation runs were dedicated to machine capacity and material handling capabilities. The system design process utilized much of the information obtained via modeling.

1. INTRODUCTION

Garrett Turbine Engine Company is a leading supplier of turbo-prop, turbo-fan, and auxiliary power units within the aerospace industry. These products are marketed in competitive environment and Garrett is constantly searching for a way to improve product profitability and customer service. As part of the organization's commitment to improving the manufacturing technologies associated with turbine engine manufacturing a Flexible Manufacturing Cell was proposed to machine cases for the above products.

Cases are the major body of a turbo-prop engine or a gear case associated with a turbine engine. They are made of aluminum or magnesium and are machined to very high tolerances. Any material handling device used to transport a Case must be designed to minimize potential material handling damage while transporting the heavy pallets required for quality production. Therefore, special attention was paid to the compromises associated with balancing quality conscious material handling design with overall throughput impacts.

Any system proposed for Case manufacture had to be expandable. As turbine engine manufacturing technologies improved, the manufacturing systems associated with these products must also improve. Manufacturing management was participating in a continuing effort directed at constantly incorporating state of the art machining and manufacturing engineering technologies into their products. A good simulation model must be expandable with the system in order to assist in evaluating potential improvements.

Approximately 180 operations were identified for flexible manufacturing cell production. Each one of these parts has a unique machining requirement. The machining centers would have 120 tool magazines for production ready tooling. Production requirements dictated total flexibility. Parts would be scheduled in sets to minimize tooling exchanges. Loading parts in specified orders to optimize set up efforts was considered too restrictive. Company mangement wanted complete scheduling flexibility. Prompt customer response was a top priority.

2. SYSTEM DESCRIPTION

Figure 1 shows the base system. It consists of two identical machining centers, a parts washer, two identical load/unload stations, a storage rack, and a material handling crane.

The machine centers have an input queue, an output queue, and a position for the part being machined. A part arrives at the machine and is immediately sent to be processed if no other part is currently within the operational envelope. A part arriving at the machine when another part is still being processed must wait in the input queue. After processing a part is held within the operational envelope if the output queue is full or it is sent to the output queue to await transport by the material crane. Part processing cycles vary from .15 to 2.5 hours with a mean of about .4 hours.

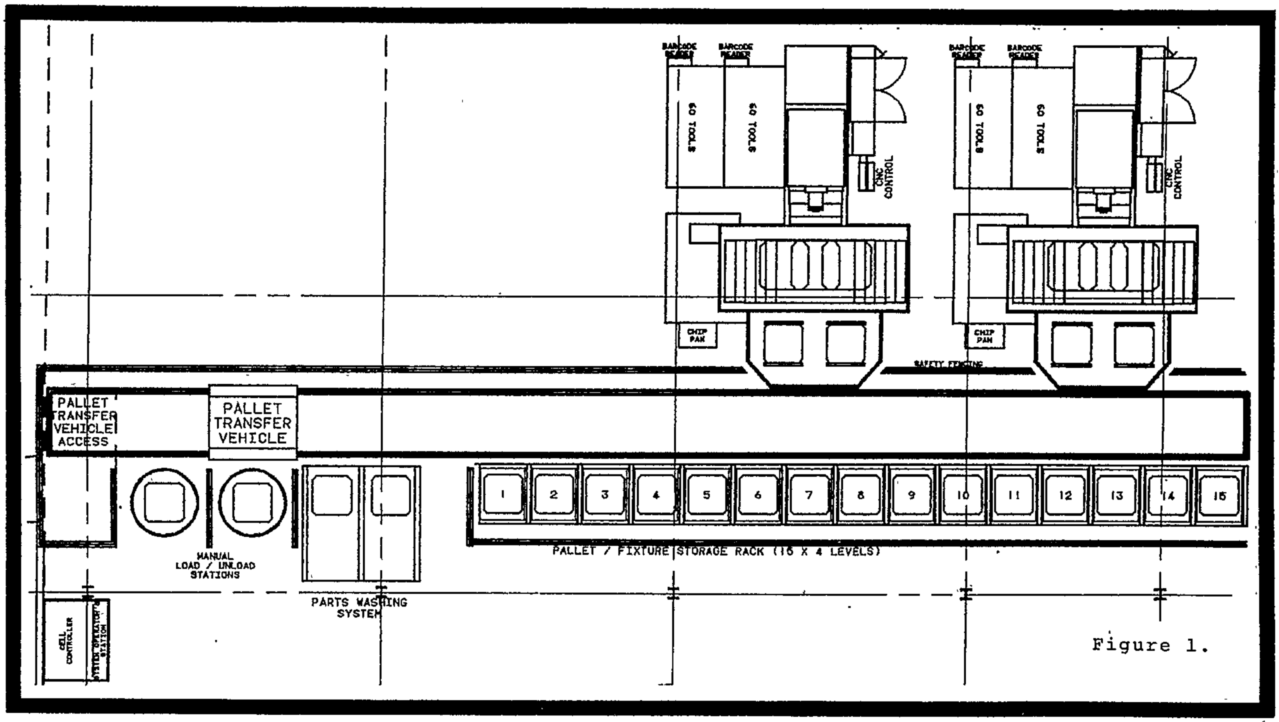

Figure 1.

The parts washer has similar part handing capabilities to the machining centers previously described. Wash cycles are the same for all parts. Process duration is 3 minutes.

Parts enter or exit the system via the load/unload stations. Parts are loaded from material handling carts onto special turntables that rotate as the operator requires while fastening the part to the fixture. Upon load operation completion, the operator signals the system via a button and the system transfers the part at its convenience. Unloading uses the same process in reverse. The actual loading and unloading is a manual operation and takes minimal time when compared to the total processing time. Load and unload times all lie within the .03 to .07 hour range with a mean of about .033 hours.

Material handling via the crane is the most complex part of the system. Parts are transported in between any two system locations via a crane operation. A case is not a particularly heavy component, however, the pallet required to hold a part in position during the machining cycle weighs in excess of 1500 lbs. A system transporter had to be able to move heavy fixtures around frequently and not become a system bottle neck. This crane was a very important design focal point. It is the controlling factor for system throughput. Special attention was given to designing it to transport parts safely and efficiently. In addition, it must be capable of supporting more than just two machines shown in the original diagram. Future plans call for the addition of two or more dissimilar machining centers and other equipment.

Crane specifications are described in Table 1. Horizontal and vertical travel could occur simultaneously as the crane was transporting a load. The system vendor provided horizontal speed, vertical speed, and extraction times. Crane Travel distances, both horizontal and vertical, were obtained by using a scaled system layouts.

Table 1: Crane Specifications

Crane movement:

Two dimensional simultaneous

Travel characteristics:

Vertical speed	60 feet/minute
Horizontal speed	250 feet/minute
Extraction cycle*	10 seconds

* Extraction time is the time required to bring a part to the crane or remove a part from the crane.

A rack system is included for storage purposes. Rack configuration is 4 rows high and 15 columns deep. The initial plans called for purchasing 44 pallets, leaving the remaining cells for future expansion. Pallets, pallet/fixture sets, parts awaiting machining, and parts awaiting unloading all use these racks. Figure 1 shows the rack placement. Additional racking can be added on the opposite site of the aisle if future system expansion requires more fixture capacity.

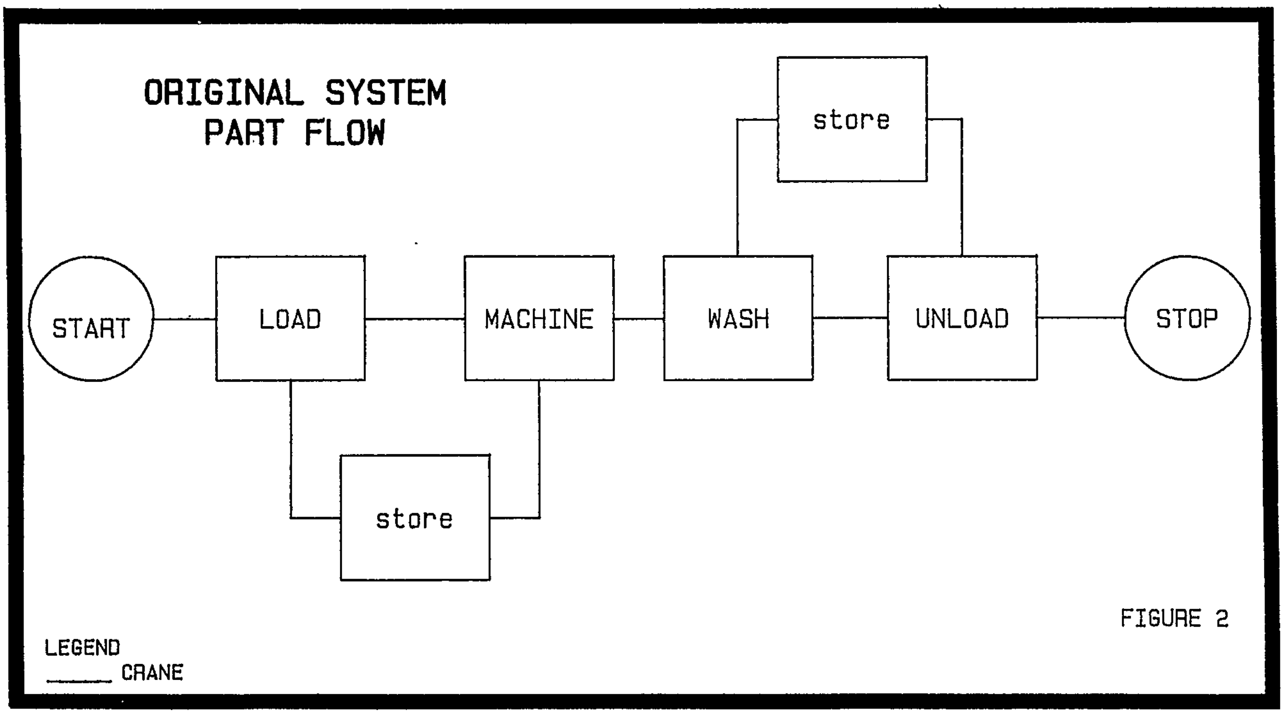

FIGURE 2

General part flow is described in Figure 2, each box represents an activity being performed and a line depicts a transport operation. The crane provides an empty fixture prior to loading a part. Once a fixture is at the load station, an operator mounts the part and indicates a loaded part is ready for processing by pressing a button. The system now makes a decision. If one of the machines is either idle or if it has room in its waiting for processing queue, the part is routed to the machine. Otherwise, the part is routed over to the storage rack and it waits for an available processing opportunity. After machining is completed and space is available at the washer input queue, the crane removes the part from the machine output queue and transports it to the washer. Washed parts can then either be sent to the unload station or returned to the storage rack. Parts are routed to the unload station if the station is empty. If the station is busy, they are routed to the storage rack. Parts routed to the storage rack are brought to the unload station as soon as the unload station is available. Storage using the storage rack is only allowed in between load and machining operations or in between wash and unload operations. Parts do not reside in the storage rack after machining and before washing. Manufacturing does not want to store recently machined unwashed parts in the storage rack. These parts might drip cutting fluids on parts residing beneath them in the storage rack and result in a quality problem. Each arc corresponds to a transporter trip. A given part might require anywhere from 5 to 7 crane trips depending on how many times a part requires in process storage.

3. EMBELLISHMENT

A second system design was also simulated. Both manufacturing management and the system vendor were aware of transporter capacity and its relationship to overall system capability. Expansion plans were not definite. Potential system modifications included adding additional cases, more machining centers, or incorporating quality control related support equipment. However, some considerations were given to decreasing transporter dependence. All parties recognized the implications associated with overloading the material handling system. Machine tools or storage capacity could be added without major system modifications, however, incorporating an additional crane on the existing track was very costly. Everyone wanted to design a material handling system capable of supporting future system modifications.

The vendor proposed a modification depicted in figure 3. Wash to unload part flow was modified to eliminate some of the transporter dependence built into the original system. Parts leaving the system go directly to the unload station via a conveyer whenever the unload station is idle. When the unload station is full parts are routed

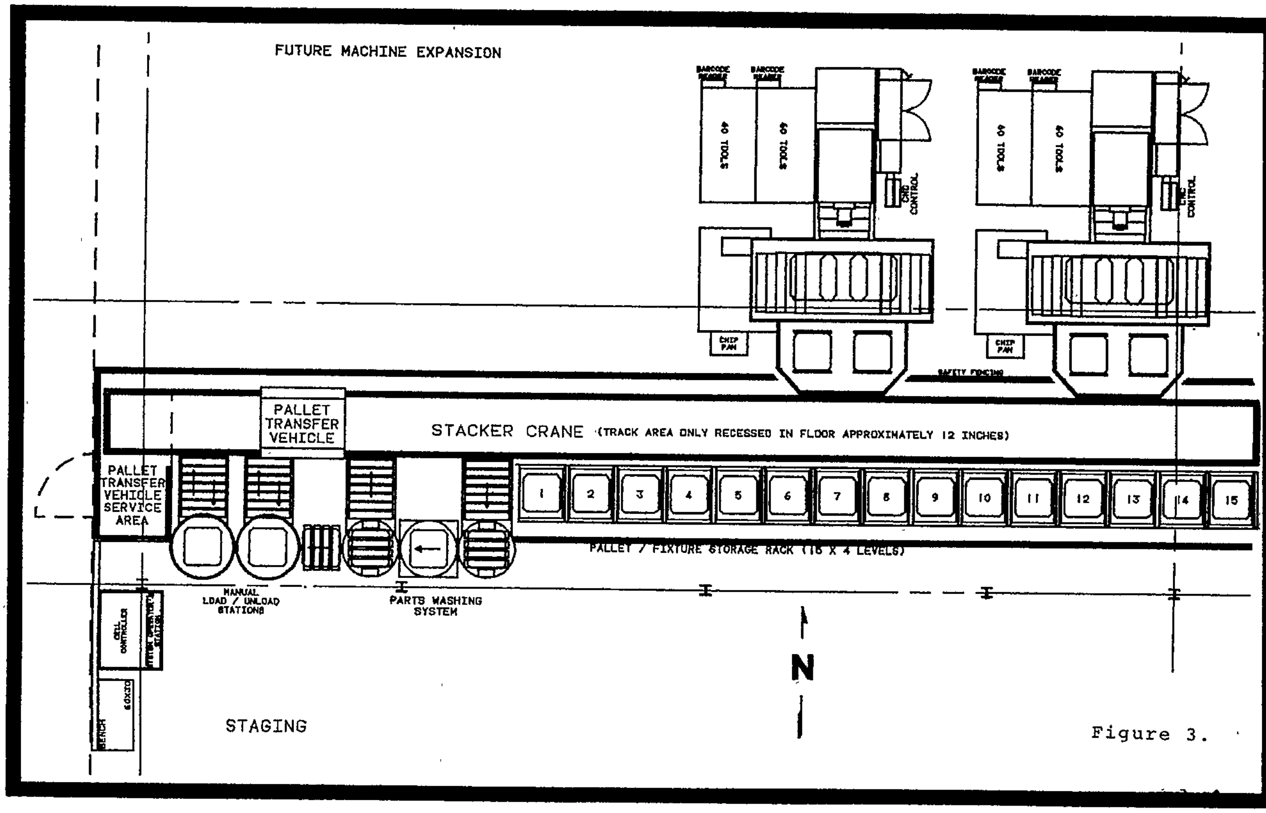

Figure 3.

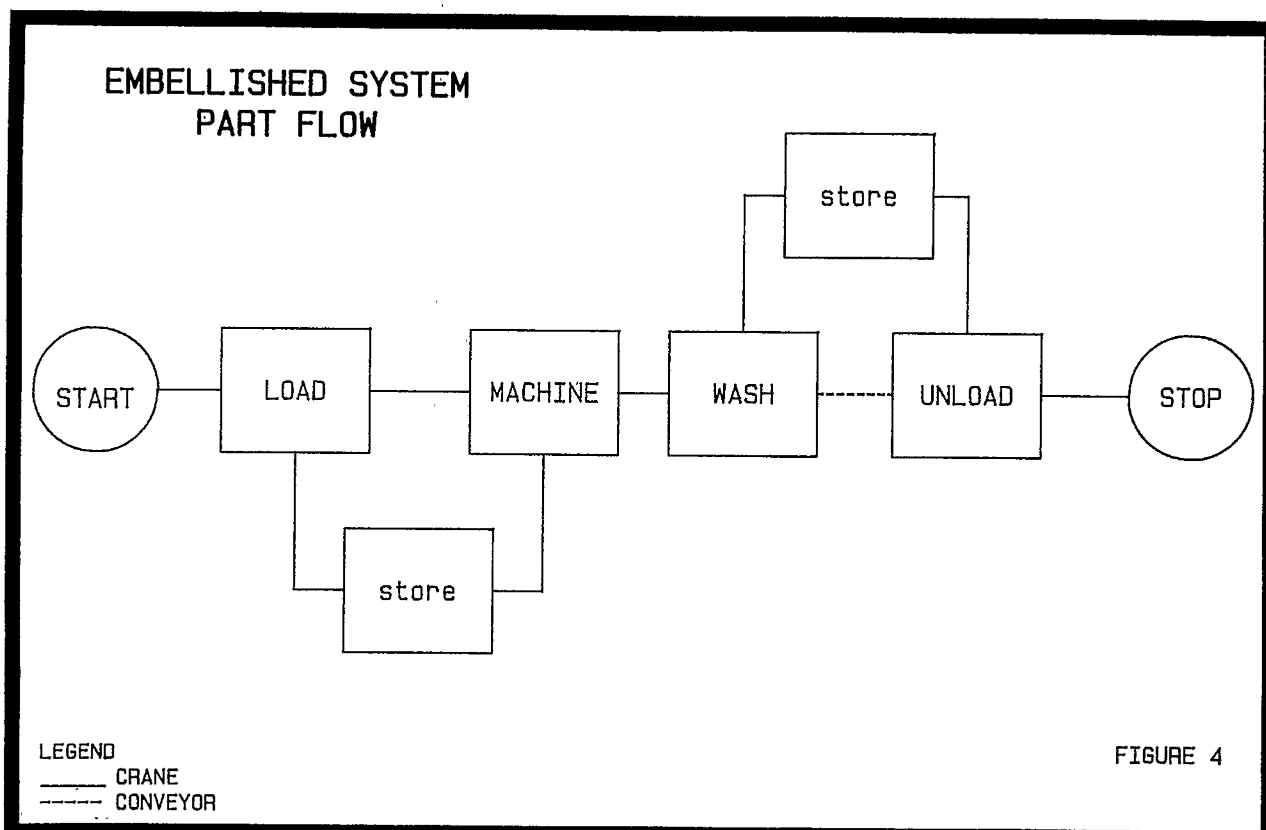

FIGURE 4

to storage as in the previous system. Figure 4 shows the revised material flow using a dashed line to represent conveyer travel and solid lines to represent crane travel.

4. SIMULATION MODEL

A discrete event SLAM simulation model was constructed to evaluate the original system and the embellished system's peformance. Model statistics are described in table 2.

Table 2: Model Statistics

Utilization	
	Machining Centers
	Crane
	Operator
	Washer
	Fixtures
Part Time In System	
Number of Parts in the System	
Input and Output Queue Status	
	Machining Centers
	Load/Unload Stations
	Parts Washer
Storage System WIP	
Throughput	

SLAM is a well known simulation language, therefore, the actual model will not be described in great detail here. This paper is designed to inform the reader about the decision process surrounding the model, instead of getting into an elaborate discussion describing model coding.

This system is almost entirely automated, therefore, random variables were not appropriate when describing machine, crane, or wash cycles. A numerical control processor directs each device and negligible variation in operating cycles is expected.

A random variable described the operator controlled load and unload cycles. These cycles were assumed to be triangularly distributed with a plus or minus 20 percent variation. There was no available data on similar operations for analysis via formal distribution testing, etc. Sensitivity analysis showed no significant changes when triangular distribution parameters were altered or a normal distribution was substituted. It was concluded that the system was not sensitive to load and unload cycle modifications within the experimental range and a triangular distribution was appropriate.

A five day three shift operation was modeled excluding holiday operations. This left weekends for any preventive maintenance, experimentation, and production overloads.

5. VERIFICATION AND VALIDATION

According to Carson "One of the most challenging and difficult aspects of the modeler's job is building an accurate model and convincing the end users that the model is a meaningful and accurate representation of the real system and thus can be used in the decision making process." Validation and verification were considered integral parts of the simulation process starting with model development and continuing through the period of actual model use. A team effort concept was used. The writer believes this team concept helped build a model with a high level of credibility.

Communication was considered the key. Manufacturing management had little experience with simulation modeling and flexible manufacturing systems. Modeling was not sold as an ultimate tool that could solve all system related design problems. The black box optimization myth was avoided. Instead simulation modeling was presented as a tool for testing alternatives. The system design team was encouraged to use the tool to evaluate different options when common sense or technical expertise would not provide a direct answer. Care was taken to avoid misrepresenting simulation as a simple process. Time estimates were not optimistically presented, instead, the modeler tried to be as realistic as possible when describing the cost and time realities involved.

A clear cut objective was developed to define simulation's role and describe how it would complement system design. It was kept simple. The initial simulation objective was: would the system manufacture the required levels of production in the allocated time? After this question was answered ideas for improving system performance were evaluated.

Modeling was initiated by attempting to define proposed system operation as completely as was possible. Several discussions were held between manufacturing management and the modeler. When details were not known, the system's operational description process was enhanced by including the vendor in such discussions. One tool that helped all parties was to write down all questions and discuss them on an item by item basis during the course of a system operation discussion. A list concept was also used to highlight any assumptions built into the model.

Once the system was defined and a model constructed the modeler used some traditional techniques to verify the model was executing as intended. Structured programming was used and event routine floor charts were found helpful when debugging the model. Sensitivity analysis was used for many initial runs with more sophisticated data being used for each successive run. During each of these runs traces and evaluation of simulation output statistics were used to analyze the model's performance.

Model validation was approached by using a thorough presentation of how the model operated to manufacturing management. Care was taken to include any model assumptions during this presentation. Output results for several manufacturing scenarios were also presented to evaluate the data for credibility. This evaluation team consisted of the modeler, manufacturing management, and the system vendor.

Unfortunately, the modeling process was not supplemented with graphical animation. Garrett did not have this capability during the model development period. Animation would have assisted with two phases. Evaluating trace data in order to ascertain what was going on within the model at a particular point in time was a time consuming process. Animation would have made this process more efficient. Showing manufacturing management how the model was functioning would have been more informative if a graphical presentation could have been included when discussing modeling validity.

6. RESULTS

The base model simulation results are shown in table 3.

Table 3: Simulation Results
Base System
For One Year Run Period

Equipment utilization:

Machine 1	.62
Machine 2	.78
Washer	.19
Crane	.16
Operator	.15

Fixture utilizations:

High	Average	Low
.24	.11	.01

Exception: One fixture was utilized at .61

System statistics:

Average number of parts in system	4.4
Average time (hours) for a part in system	1.1
Total throughput (parts)	23000

Machining centers 1 and 2 show utilizations under 80 percent. The washer, crane, and operator are all utilized under 20 percent. None of the fixture utilizations exceeded 24 percent with one exception. Approximately 23,000 parts were processed during the year with an average of 4.4 parts in the system. Each part spent an average of 1.1 hours in the actual system.

One fixture showed a 61 percent utilization. Because it had several different parts associated with it. Manufacturing management decided to add 2 more identical fixtures and bring the utilization into line with the other fixtures. When the model was run using these additional fixtures utilizations were within the 1 to 24 percent range.

The embellished system results are shown in table 4. The major difference is a crane utilization of 14 percent.

Table 4: Simulation Results
Embellished System
For A One Year Run Period

Equipment utilizations:

Machine 1	.62
Machine 2	.78
Washer	.19
Crane	.14
Operator	.15

Fixture utilizations:

High	Average	Low
.24	.11	.01

System statistics:

Average number of parts in the system	4.4
Average time (hours) for a part in thesystem	1.1
Total throughput (parts)	23000

7. CONCLUSIONS

Both systems can run the required production however, the additional fixtures must be added. Equipment utilizations and system statistics are within acceptable levels. All equipment has an ample safety margin.

Management must take a careful look at all costs associated with incorporating the embellished system. Conveyor based part transportation reduces overall crane activity by 2 percent. If future system modifications increase crane activity to bottleneck levels, conveyor based part transportation may eliminate the need for costly system expansion due to additional crane requirements. Taking a thorough look at potential system expansion is recommended. Devising a future expansion strategy would assist in deciding whether or not to incorporate conveyor based pallet transfer. If the expansion strategy does not increase crane requirements dramatically, then the original configuration is acceptable.

This model's success can be attributed to a team approach. All phases of system description, model validation, and incorporation of the existing results were a group effort. Any modeler working with a prospective client should give serious consideration to adopting a group strategy. Group orientations are also extremely beneficial when the group is unfamiliar with modeling and/or developing systems with high degrees of interdependence.

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