

SIMULATION ASSISTED DESIGN AND INSTALLATION  
OF  
A FLEXIBLE ASSEMBLY SYSTEM

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## ABSTRACT

The successful implementation of a Flexible Manufacturing/Assembly System can be an effective means of reducing labor, resources and work-in-process inventory. It can increase equipment utilizations, improve quality and result in increased throughput. Simulation is an effective tool for analyzing critical system components and their inter-relationships; consequently, ensuring systems design meets throughput requirements at reduced costs. This paper presents an approach to the design, specification and implementation of a Flexible Assembly System (FAS) using simulation. It presents a practical approach for designing manufacturing systems involving uncertainties. Two simulation models are discussed:

- (1) a GPSS/H model and
- (2) a PCMODEL model.

The GPSS/H model was used during the early FAS design and specification stage. The PCMODEL model was used to "sell" the proposed FAS configuration to management. The FAS has been successfully implemented.

## 1. INTRODUCTION

Flexible Manufacturing is becoming popular and in more widespread use in manufacturing companies. The term Flexible Manufacturing System (FMS) is used to mean anything from the use of CNC machines or robots, to totally automated factories. Although there is no measure to determine if a manufacturing or assembly system has the capabilities of an ideal FMS, the capability of the system to adapt to unpredictable changes makes them flexible (Wortman, 1984). Flexibility as defined in this paper is classified as:

- (1) Machine Flexibility
- (2) Routing Flexibility
- (3) Product Mix Flexibility
- (4) Operational Flexibility
- (5) Production Flexibility
- (6) Expansion Flexibility.

Typically, Flexible Manufacturing Systems consist of workstations capable of performing different operations combining automated, semi-automated and manual operations. Usually, manual operations involved in an FMS are unloading/loading, inspection, assembly and output handling. A central computer may be used to schedule, monitor and control the entire FMS.

The number of feasible FMS configurations may be quite large. A "acceptable" FMS configuration should be able to meet production goals in an "optimum" manner. The best solution is not easily identifiable, and the best way to attain a solution is to compare alternate designs and procedures. Obviously, actual

demonstration of potential FMS solutions is virtually cost prohibitive due to the large investment involved in a FMS. In order to develop an appropriate and cost effective FMS solution, one needs a planning tool which permits the study of the dynamic nature of a FMS.

Many tools have been used in the analysis of conventional systems. Perhaps the most frequently employed tool is experience. However, with the emergence of FMS technology, fewer personnel with experience are available. Actual system experimentation is another potential tool, but it is usually economically infeasible. Operations Research models are increasingly being developed for manufacturing systems. However, the usual production problems associated with a FMS, belong to a class of problems termed as "NP complete", i.e., computationally intractable.

Simulation is the right tool for a detailed analysis of a manufacturing system (Lenz, 1985). The primary benefit of simulation in manufacturing is that simulation allows a global view of system performance or the effect of changes in systems performance. A global systems approach enables one to avoid focusing on subsystem performance to the detriment of overall system performance (Law, 1986), (Mills and Talavage, 1985), (Nagler, 1987). Simulation is capable of representing the logical conditions, processing rules, and the scheduling constraints in the FMS. Also, simulation allows one to depict the dynamic and stochastic nature of the real system, and to answer "What If" type questions. Simulation can be considered as a process of experimenting on a surrogate system for the real world system.

## 2. SYSTEM CHARACTERISTICS

The operational scenario for the FAS is described below:

The operator pushes a button that signals the system that she/he is ready to build another part.

The system will release pallets to the operator to begin the subassembly.

The operator then proceeds with the manual portion of the build for each part.

The operator releases the pallets to the conveyor.

The RF tag transceiver reader reads the RF tag on the pallets.

The parts proceed down the line in sequence in an asynchronous nature.

The parts enter the pre-testing station.

The pallets exit and proceed down the conveyor.

The pallet enters additional hard tooling.

The pallet enters the first robotic cell.

After the cell completes the intended operation, the pallets exit and proceed down the conveyor.

The pallets enter the 1st check station. This station checks for the operations completed by the 1st robotic cell.

The pallets exit and proceed down the conveyor.

The pallets enter the 2nd robotic cell.

After the intended operations are completed by the 2nd robotic cell the pallets exit and move down the conveyor.

The pallets enter the 2nd check station. This station checks for the operations performed by the second robotic cell.

The pallets exit and proceed down the conveyor.

The pallets enter the third robotic cell. After the completion of the intended operation, the parts exit and proceed down the conveyor.

The pallets enter the 3rd check station. The station checks for the operations completed by the third robotic cell.

The pallets exit and proceed to the next station.

The pallets enter the fourth robotic cell. After the operations are completed the pallets move further down the conveyor.

The pallets enter the fourth check station. The station checks for the operations completed by the fourth robot station.

The pallets exit the check station and proceed down the line.

The pallets enter the rivet station. The pallets with the parts have rivets inserted and clinched.

Any defective parts enter the Repair station and wait for the operator to attend. After the defects are fixed up the parts join the regular good parts on the conveyor and move along with them further.

The pallets enter the printer station where product information is encoded onto the part.

The pallets exit and proceed down the conveyor and enter the testing station area.

The pallets check the first testing station and see if there is enough space for it to enter. If so, they enter the testing station 1.

The pallets that were unable to find a place in the first testing station check for space availability at the second testing station. The pallets which have been tested at the first station keep moving down the conveyor line.

At the end of all the testing stations, the pallets that have not been tested enter the overflow return loop and rejoin the input queue of

the first testing station to try again.

The pallets exit and proceed down the conveyor to the final rivet station.

After the riveting operations are completed, the pallets exit and proceed down the conveyor.

The defective pallets (testing defect) enter the repair station for repair.

The good pallets proceed to the first quality control final test station. The repaired pallets rejoin these parts at this point.

The parts that are selected to be checked enter the quality control final test station.

If there is no space available, the parts that needed to be checked enter the overflow loop and rejoin the input queue of the quality control final test station and repeat the same process again.

The pallets enter the packing station.

After the completion of the intended operations, the parts leave the pallets and exit the system.

The empty pallets proceed down the conveyor and join the manual sub-assembly station.

### 3. PHASE I : A GPSS/H SIMULATION STUDY

As an aid to the design of the proposed Flexible Assembly System (FAS) whose operational scenario is presented in the previous section, a simulation model was developed using GPSS/H, and a simulation experiment was designed. The GPSS/H (Henriksen and Crain, 1983), (Schriber, 1974) model for the proposed FAS was built using facilities, storages, functions, matrices and logic switches. The transactions simulated the part types moving through the system. Each part type (transaction) is tagged, for the processing time at certain workstations vary according to part type. Each workstation was modeled as a facility. All the buffers between the workstations were modeled with storages. Parts stay in the buffers (storages) until they are accepted by the workstation (facility). Each buffer (storage) represents a physical section of the conveyor and, hence, determines the physical layout of the FAS. Function entities modeled the probabilistic variables in the FAS, such as, the yield data and the number of components fed before a feeder jam.

GPSS/H macros were used to model some elements of the FAS, such as, quality control final test stations. The macros allow one to modify easily the number of quality control final test stations, for the number of quality control final test stations was to be determined as a result of the simulation study.

Separate model segments were used for tending operators (facilities), failed parts (transactions) and robot feeder jams (transactions). Each feeder jam was modeled distinctly which led to a straight forward model and to an easy interpretation of model results.

The simulation study examined the operation of the system under "best" and "worst" case scenarios. In other words, the robustness of the system with regard to maximum attainable performance was explored. The primary objectives of the simulation study were:

To establish buffers between workstations which enable the system to attain maximum throughput

To identify constraining operations and to explore cycle time modifications

To identify sources of bottlenecks

To determine the optimal number of testing stations

To find the optimal number of quality control final testing stations

To estimate the number of tending operators

To compute the number of manual builders

To estimate the required number of pallets.

The minimum number pallets carrying parts required by the system was an important variable. In the simulation model each pallet was a transaction and each transaction from the manual builder to the unloading workstation was a member of storage of unlimited capacity. Using this approach no workstation is starved for pallets. Each simulation run for product mix and test option yielded the maximum number of pallets. So, the maximum number of pallets was equal to the maximum over all the runs.

Every part had to be tested at a test station. Each test option was represented by the distribution of the number of passes through the test station. Every part was retested at the same station on which it failed. The test stations were arranged in series and parts entered the first buffer that had space available. A feedback loop connected the last and first test station. Each part remained at the same test station until it passed the test. For the worst product mix and test option, the simulation model indicated a bottleneck in the system. A careful examination indicated that the cool down time ( the time between the completion of a test and the initiation of the next test for the same part) was too large. The bottleneck was further amplified by the "worst case" test option which had a large percentage of parts being tested two or three times. Two solutions were available:

- (1) increase the number of test stations, or
- (2) reduce the "cool down" time.

The first solution was too costly. Therefore, a different "cool down" option was proposed using forced cooling that reduced the time by a factor of two. Although the bottleneck was reduced, the FAS still could not produce parts at an acceptable rate. Finally, an additional test check station was added with forced cooling. Even after the reduction of cool down time and the addition of the test station a bottleneck was still occurring because of the timing of parts flow in the test station. The solution was to restrict the number of parts at any test station ( testing plus buffers) to be one less than the maximum using sensors. The net effects were the following:

- (1) The simulated FAS operated without bottlenecks even for the worst cases of product mix and test options.
- (2) The FAS throughput was doubled.
- (3) The last test station had a very low

utilization for the best cases of product mix and test option.

The arrangement of the quality control final test stations was similar to the arrangement of the test stations. Initially, each quality control final test station was designed with input queues and output queues with capacities of two and eight, respectively. The quality control final test cycle times were long and the input queues filled quickly resulting in a considerable number of parts in the feedback loop and a reduction in throughput. The capacities of the input and output queues were reversed, and the problem was remedied.

The input to the FAS is fed by manual builders or subassemblers. Throughput will be low when not enough manual builders are present. As a result of the simulation runs, the number of manual builders was appropriately determined for the FAS, for the idle time was low and the FAS was not starved for parts.

#### 4. PHASE II: A PCMODEL SIMULATION STUDY

Although some considerations were given to the economic aspects of the FAS system design during PHASE I, the primary objective of PHASE I was to analyze capacity requirements in order to maximize throughput. System design decision regarding the number of test stations, manual builders, quality control final test stations, etc. were determined in order to maximize throughput given the product mix, yield, etc. parameters. The resulting FAS was more costly than the one in initial projections, for the initial system could not produce parts at an acceptable rate. Also, some preliminary workstation parameters used in PHASE I such as cycle times and yield rates were still uncertain.

In order to "sell" the FAS configuration to management, a further animated simulation model was developed in PCMODEL (SIMSOFT, 1988). Although management was aware of the benefits of simulation, it was felt that more output than statistics, tables, charts and graphs were appropriate. An animated simulation model enhanced the visualization of the FAS operation and of the problems associated with design alternatives.

##### PHASE I and PHASE II Differences:

1. Machine cycle times
2. New workstations were added
3. Layout was altered
4. Due to the animated model, vendors realized the level of data demanded by simulation, and more detailed data was supplied for machine operations.
5. New product mixes were formulated.
6. The distribution of feeder jamming was not altered.
7. Material handling specifics were added to the system.

A PCMODEL simulation model of the new FAS was developed and runs were made for several product mixes. The maximum work-in-process-inventory (WIP) was limited to 230 pallets. Since each product mix possesses different cycle times and test times, FAS performance varied from mix to mix.

The animated model gave the modeler hours of experience observing system operations. Hence, one obtained a "feel" for how the FAS will operate upon installation. Typical examples follow:

WIP has to be balanced for individual product mixes to ensure smooth flow.

Operators will have to react to variations in FAS operations such as bottlenecks even with no changes product mix because of the inherent variance in the system parameters.

Starving and blocking may occur at the manual assembly area, so the number of manual assemblers may have to be adjusted on a shift by shift basis.

The increase in maximum WIP may not increase throughput.

Feeder jam clearing need priority over other tending operator duties.

## 5. CONCLUSIONS

Simulation modelling and analysis proved to be an invaluable tool in the design and implementation of a Flexible Assembly System. Preliminary simulation models allowed system designers to specify the proper quantity and quality workstations to achieve production rate goals. An animated simulation model helped "sell" the FAS to management, gave systems engineers operational experiences with the system and improved communications with potential system component vendors, and gave system engineers quality data from which to negotiate system component characteristics. FAS system engineers and management gained confidence in their belief that the system will operate as specified. Finally, the estimated saving due to the use of simulation versus alternative analysis tools was in excess of \$500,000 in total FAS design and installation cost.

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