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M. Abrams, P. Haigh, and J. Comfort (eds.)

The MAST simulation environment analyzing low frequency inventory systems

John E. Lenz
CMS Research, Inc
600 S. Main Street
Oshkosh, WI 54901

and

James R. Gross
College of Bus. Admin.
Univ. of WI-Oshkosh
Oshkosh, WI 54901

ABSTRACT

Many of today's manufacturing facilities incorporate the latest manufacturing technology including machine tools, fixturing devices, tooling, communication networks, computer software and operators. The integration of these islands of automation into one system is a technology within itself requiring "state of the art" tools to ensure proper compatibility between and among components. When this integration is treated as a technology separate from the technology of individual components, specially developed design tools are necessary to explore these unique characteristics. One such tool combining the desirable characteristics of minimal data input, high flexibility in simulating various system configurations and output results directed at specific characteristics of integrated manufacturing is the MAST Simulation Environment, Release 2.

The complete MAST environment is comprised of four integrated software programs: SPAR, MAST, BEAM and BOAT. Each of the four programs performs specific tasks needed in the design cycle for a manufacturing system. As an integrated whole, these four programs combine to form a design/analysis environment uniquely suited for the study of manufacturing systems.

The SPAR module allows input of part production and process plan for all part types to be run in the FMS. From this input, the number of stations, transporters and pallets can be determined. These results can be adjusted using a "full screen" editor until a feasible system configuration is reached. SPAR will then automatically generate data for the MAST simulation language.

With the SPAR generated date, MAST will simulate each part motion, transporter movement, station status and the actions of tools and operators. Upon completion of the simulation, performance statistics can be printed, graphically displayed, or the activity which took place in the simulation can be animated. A detailed schedule of parts and their operations is recorded for each work station. This can be displayed graphically in the form of a Gantt Chart or representative part traces can be taken. These traces show the elapsed time comparative parts incur during their process through the manufacturing facility.

The third program is BEAM which "plays back" the simulation activity with graphical displays of part production, station utilization and transporter utilization.

Finally, BOAT (Best Over All Tool) provides an expert system shell which assists the user with problem formulation by remembering steps which have been taken and suggesting the next step. It also provides expert analysis of results based upon the Manufacturing Integration Model (MIM). MIM is a theoretical result relating system flexibility, inventory and throughput.

INTRODUCTION

Most design tools used in manufacturing productivity are outgrowths of tools which are used in job shop and assembly line applications. The mathematical models of job shops and rigid flow models of transfer lines are not suitable for the unique characteristics of low inventory unbalanced production. Because integrated manufacturing uses low inventory and unbalanced operation, it becomes a technology all of its own.

This new technology must have design tools which allow study of its unique characteristics. These characteristics include flexible paths through the system, interactions between an asynchronous transportation system and machines, station blockage, real-time control algorithm compatibility with the system configuration and the flexibility of the work force. No tool which was originally intended for general manufacturing has the capability to study these unique features, therefore, the new technology of integrated manufacturing requires new design tools.

One such design tool solely intended for low inventory-unbalanced production is The MAST Simulation Environment. It consists of four software programs, each of which is described in the following sections.

System Planning of Aggregate Requirements

Many capacity planning tools exist for manufacturing systems, but most of these have not been enhanced for the unique characteristics of integrated manufacturing. In traditional planning methods, a part is defined to require machine and transport time. However, the SPAR model extends this evaluation to include the amount of in-process storage capacity which might be required. This extension is necessary for accurate evaluations of low inventory systems because parts must be tracked and stored even when they are not at a machine and in operation.

The aggregate planning procedure within SPAR is designed to compute the gross requirements of the planned production and compute its capacity in three distinct areas. First, the station requirement is computed from the cumulation of operations assigned according to the process plan, the amount of time required to perform a pallet exchange and the production requirement.

Secondly, the transporter requirement is computed from the cumulation of the average cycle time for a transporter to pick-up and deliver a pallet times the number of transport moves required according to parts and routes represents the total transporter requirement.

The third requirement computed within SPAR is the amount of work in-process required to meet production targets. In-process storage within the manufacturing facility includes the elapsed time when a part has completed an operation and is waiting for transportation or has completed transportation and is waiting for a station. This time is estimated for each part type and is used to estimate a flow time through the facility. This time is used to compute an initial estimate of the number of pallets needed from the production requirement assuming a uniform production level during the planning period.

Respective station, transporter and work in-process requirements are compared to each of their respective capacities. the station capacity is determined by multiplying the number of stations of each type by the planning horizon. The transporter capacity is computed by multiplying the number of transporters by the planning horizon. The storage capacity is assumed to be sufficient to store the total number of pallets and thus no comparison is performed within SPAR. The storage capacity is used to indicate to the designer the amount of storage necessary to meet the planned production within the planning horizon.

When the requirements of the station and transporters are less than their respective capacity, the production plan is considered feasible within the planning horizon. But if any one of the requirements exceed its respective capacity, the production plan is considered infeasible and a strategy must be invoked to bring the system to a feasible configuration.

SPAR contains four distinct strategies for bringing a manufacturing facility into a feasible capacity configuration. These include extending the planning horizon, reducing production quantities, adding stations and transporters, and adjusting part routes. SPAR automatically computes the first three strategies upon the designers request. With respect to altering part routes, too many alternatives exist and thus the designer is left to attend to this through the use of the built in editor within SPAR.

Once a feasible system has been designed, SPAR can automatically produce data input for the MAST simulation. The parts and their process definitions are recorded from the data already provided. All that is needed is a description of the layout of the facility, roles of operators and scheduling algorithm selections. The layout is defined through the use of points and distances between these points. Teams of operators can be assigned to groups of work stations and scheduling algorithms range from random mix to batch. The result of this generation is a data file ready to be read directly into MAST for simulation of all activity in the proposed FMS. Thus, SPAR acts not only as a preliminary system design tool but also as an interface between the modeler and the MAST simulator. The following section describes the features of the MAST simulation language.

Manufacturing System Design Tool (MAST)

The MAST simulator contains a generalized model for integrated manufacturing systems. This model contains features for representing the system hardware components and the control hierarchy. The hardware model can study multiple part families, a variety of station types, conveyors and/or carts, numerous in-process storage devices, and any system layout. The hardware model is completely described by the data input and no "modeling" or programming is required.

Along with this hardware model, MAST also contains a model for the computer control or a software model. In this model, the actual control is broken into seven distinct decision areas. For each of the decision areas, MAST contains a library of algorithms. For example, it is possible to switch from cart material handling to conveyor by simply changing one algorithm in the transportation selection decision. The seven decision areas are listed below.

Scheduling. This algorithm is called upon whenever a part can be introduced into the system. Algorithms within MAST include such options as random mix for all part types, assembly and disassembly of part types and batch production.

Operation Sequence. This decision occurs whenever a part has completed an operation and must determine which operation is to be performed next. Algorithms within MAST include fixed sequence, buffering to intermediate storage positions, or operation sequence based upon station availability.

Station Selection. This decision is made whenever a part has found its next operation and one of several stations must be assigned. Algorithms in MAST include highest priority station, idle station, closest station and lowest backlog.

Transporter Selection. This decision involves a part which has found a next operation and station and is ready for transportation. Algorithms within MAST include idle cart, closest cart, conveyor or synchronous conveyor.

In-Process Storage Control. This decision is made whenever a part must wait for a station or transporter. Algorithms in MAST include first in-first out, priority ranking or fixed sequence.

Traffic Control. This decision is made whenever a cart is requested to pick-up, deposit, or relocate to another zone. Algorithms within MAST include a push-pull control, bi-directional trunk line movement or sidings off main loop.

Tooling Control. This decision occurs only when tool data has been provided via SPAR data collection and a tool has reached its user-specified warning point. Algorithms in MAST include 100% replacement of tools, 100% replacement and replenishment/replacement with batch scheduling.

The combination of the options available in the seven areas described above provides a high degree of flexibility. This flexibility in describing a manufacturing facility makes the MAST environment easy to use, but the results or outputs must be as easy to understand. The effective use of simulation requires that results can be used with confidence. MAST contains reports which are designed specifically for the needs of manufacturing system evaluation. Component utilizations are included as well as part performance, pallet utilization and station blocking. Each of the performance measures are described below.

The first report produced by MAST is the production summary report. This report contains a list of all part types and number required, completed and scheduled along with average, minimum and maximum flow time while in the system. This flow time can be compared directly to that which was targeted in SPAR. This time in system is then reported as comprised of three separate times and is referred to as part performance.

The part performance report lists each part type and reports the average, minimum and maximum time a part spent at stations, in the material handling and in storage. The sum of these averages is equal to the average time in the system. MAST also reports these results as percentages of the system time. The next summary report lists all the pallet/fixture types and indicates the average number used and maximum number entered into the system.

As an operation is finished in MAST, it is recorded as part of operation statistics. Each station is listed and the frequency of each operation, total number of operations and total time in operation is reported. This total time is also reported as part of the station utilization report. A schedule for the individual station can be printed or displayed as a Gantt Chart.

The station utilization report includes total time and percentage of time each station is busy, shuttling a pallet, idle, down and blocked because of congestion. The busy time includes only operation time while the blocked time is the additional time a pallet stays on the work table either waiting for transportation or for a shuttle position to become vacant.

Following the station utilization report is the average queue time report for each station. These averages indicate relative occupancy and can be used to identify where congestion might be "snowballing" through the system.

The final performance report is the utilization of each transporter. Transporter utilization is reported on total time and percentage of movement, shuttling pallets, idle or down. Other statistics include total distance moved, number of assignments, average move distance and average move time. Despite this complete reporting of system performance, summary statistics only provide a view "after the fact". This is adequate for measuring congestion and realistic capacity of the system, but is not most effective in evaluating the compatibility of the control algorithms. For this evaluation, a color graphic animation of the simulated activity is used.

Background and Enhanced Animation for MAST

Many alternative algorithms exist for each of the seven decision areas within the supervisory computer control. It is essential that these algorithms be evaluated for "optimality" just as it is important to study the operation of the hardware. In many instances, the machinery is selected and the computer control is ignored during the design. Two reasons exist for this incomplete design approach: 1) Computers are assumed to be easily programmed to do anything and, 2) Evaluation of different algorithms via statistical output is difficult. Simulation of detailed operation is needed to study the integration effects of the manufacturing facility and graphic animation provides a visible tool for review of operation.

Background and Enhanced Animation for MAST (BEAM) has the capability to generate a background from the data input for MAST and to animate all activity which took place within a MAST simulation. The background generation produces a graphical layout of the FMS on the computer monitor. This background is quickly obtained through use of either a mouse or arrow keys in a CAD-like fashion. The process requires identifying the appropriate placement in the screen for track zones and boxes for station work tables. Queues are shown as an area between the work table and the track.

The second task for BEAM is the animation of the MAST simulated activity. The animation is accomplished by "blinking" images through the background according to the event activity. The event activity is recorded in a file which is read by BEAM.

Circles with ID's are used to indicate each specific part type and transporters are described with colored boxes. The animation can be played at various speeds from real time to viewing eight hours of activity in eight minutes of time. As the animation runs, it is also possible to display system performance statistics.

BEAM provides graphical displays of the performance statistics as these are accumulated. These displays include a bar chart showing production requirement, number completed and number scheduled. The part performance is displayed using a pie chart with three sections, one for station time, storage time and material handling time. A line graph of production over time is available for each part type and a summary of total production for the FMS. Station utilization is reported with pie charts for individual stations and station groups. These pie charts show time busy, shuttling, idle and down. Finally, transporter utilization is shown as time moving, shuttling, idle and down in a pie chart. The actual amounts are displayed along with each graphic.

Best Over All Tool (BOAT)

BOAT provides an interface to the use which assists in problem formulation, modeling and interpretation of results. Assistance with problem formulation is accomplished by providing a single menu for all features in SPAR-MAST-BEAM. This main menu remembers all the steps which have been taken and "suggests the next step" by defaulting the response. BOAT assists in modeling by providing information about similar case studies and methods which were used. Last, BOAT utilizes the Manufacturing Integration Model (MIM) for comparing the SPAR results to the MAST simulation results. The basic principle is that SPAR results to the MAST simulation results contain targets based upon mathematics whereas the MAST simulation results contain performance results which include integration effects. The difference between these results is a quantification of the integration effects present in the manufacturing facility. MIM provides a framework for comparing these results and is fully described in Reference 4.

SUMMARY

The design of integrated manufacturing must be treated as a technology within itself because of the integration of many "state of the art" technologies for manufacturing. Design tools which treat this as a separate technology are in short supply but are critical to the future of low inventory manufacturing. One design tool is The MAST Simulation Environment, Release 2. This environment includes four software programs: SPAR, MAST, BEAM and BOAT. Each of these serves a separate but integrated purpose in FMS design.

SPAR is used to "ball park" a system design. Capacity planning techniques are applied to the unique characteristics of low inventory manufacturing to study station and transporter loadings and estimates are given for the work in-process level.

MAST contains a general model for manufacturing which allows simulation of each part motion and transporter movement by data description alone. This data description can be generated via SPAR, eliminating a time-consuming task. MAST produces a complete set of performance statistics on part production, part performance, pallet utilization, operations performed, station utilizations and average queues and transporter utilization. MAST can also generate a record of all activity which can be "played back" with BEAM.

BEAM can generate a background layout of the FMS being simulated in MAST and can read an activity file from MAST to animate all motion in the FMS. This animation can be run in real time or up to 100 times faster than the actual system. During the animation, graphical displays of system performance are available.. These include bar graphs, pie charts and line graphs to display production, station utilization and transporter utilization.

BOAT provides user assistance in problem formulation, model building and analysis of results. This role is needed to ensure that the problem of manufacturing productivity remains as such and does not turn into one of getting the simulation to run.

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