GPSS V Model of a Computerized Manufacturing System

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Abstract

The role of simulation in the design of a Computerized Manufacturing System is analyzed. A case study of a particular application is given. The rationale for selecting a particular simulation language is presented. Several useful methods of representing the simulation output both in terms of actual movement of system elements and aggregate statistics are demonstrated. The validity of the results of the case study is discussed.

INTRODUCTION

The problem of designing Computerized Manufacturing Systems in such a manner as to attain high overall system productivity while maintaining adequate system flexibility and low system cost is formidable. Part of the difficulty associated with designing these systems results from the interdependence of the system components. This interdependence makes it difficult to accurately estimate system productivity prior to construction of the system. Also, this interdependence makes it difficult to evaluate the cost/productivity trade-offs inherent in the selection of various system components.

Overall system complexity and interdependence not only makes the design process more difficult but also complicates system operation. The system interdependencies make it hard to estimate the effect of changes in part mix or balance of machining operations on system productivity without running the parts on the system.

The problems resulting from the intrinsic complexities of Computerized Manufacturing Systems can be alleviated through the use of computer modeling. Construction of a model of the system which embodies the system interdependencies will allow the designer to design a system which is more cost effective and enable the system operator to more accurately estimate the effect of changes in part mix on system productivity.

What is required is a model capable of giving an accurate evaluation of machining system capacity and of providing sufficiently detailed system operating information to allow evaluation of intricate design trade-offs.

MODELING LANGUAGE SELECTION

Simulation modeling is a viable method of analyzing complex systems. The experience of the various manufacturers of these systems clearly demonstrates the value of simulation in analyzing system design and control strategies. (6, 7, 10, 11, 16, 27)

The simulation methodology used to implement the above model must be flexible so that a variety of system plans can be simulated and evaluated. Also, this tool should be capable of including enough detail so it represents every pertinent characteristic of the actual system. The flexibility of the simulation language is an especially significant factor, since the model is intended to be used for several purposes during system development.

The nature of the modeling problem seems to suggest the use of a discrete rather than continuous simulation language. However, as can be seen from Figure #1 (1), this determination narrows the field only slightly. The following are important criteria for simulation language selection. (8, 23, 26)

1. The language must be able to handle a discrete change model.
2. The language must have adequate documentation:
    a. Basic primer.
    b. Reference manual.
    c. Worked out examples and exercises for the novice.
    d. Complete description of how to get a program to run.

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2. (Continued)

    e. Elementary and sophisticated hints.

3. The language must have well developed diagnostic aids (when required).

4. The language must make efficient use of memory (otherwise the size of problem that can be handled will be restricted).

5. The language must be compatible with PDP-11 or IBM 370 computers. (Requirement unique to this application.)

6. The model developed must be capable of easy modification and extension for implementation of control strategies.

7. The language should have a well-established support group that maintains the language and is available to answer technical questions.

The GPSS (General Purpose Simulation System) simulation language was chosen to implement the model for this Computerized Manufacturing System. This simulation language fulfills all the criteria for simulation language selection. GPSS is a discrete change language and is transaction flow oriented. This simulation language is run primarily on IBM computers and is fully supported by IBM. Numerous GPSS training courses are available.

One of the primary strengths of GPSS is the ease of learning. GPSS uses a standard flowchart which is easily encoded into GPSS simulation language. These flowcharts facilitate model concept articulation. The current version of this language available from IBM is GPSS V. This version allows GPSS to interface with user written FORTRAN subroutines or PL/1 procedures via the HELP block. (18)

DESCRIPTION OF THE COMPUTERIZED MANUFACTURING SYSTEM

The GPSS V model depicts overall movement and machining operations on the manufacturing system shown in the Computerized Manufacturing System diagram in Figure #2. This manufacturing system consists of two 7" horizontal boring mills with toolchangers, four 6" horizontal boring mills with toolchangers and one boring machine. Pallets containing workpieces are transported between machines via a 32-station conveyor system. Pallets are loaded onto machines and transported across the conveyor line via nine shuttle mechanisms. There are two types of pallets in the system; pallets for machining the top of the workpiece and pallets for machining the bottom of the workpiece. Raw pallets are loaded with workpieces at a load station at the front of the conveyor line. Half machined workpieces are reloaded and finished workpieces are unloaded at the combination reload/unload station at the end of the conveyor line. Machining is done on workpieces in the sequence shown in Figure #3.

THE GPSS V MODEL

The GPSS V model utilizes FACILITIES to model the machines, shuttle mechanisms, load station and unload/reload station. The conveyor system stations are modeled using GPSS V STORAGE blocks. The transactions circulating in the model are analogous to the pallets in the machining system.

The flowchart in Figure #4 depicts the flow of transactions through the model. On the following pages a brief description of the functions of the blocks in this diagram will be given.

1. Block #1 - Model Initialization

    The function of the Model Initialization routine is to introduce the transactions, representing the empty pallets on which parts are to be loaded, into the system. In the basic model there are ten pallets (five for tops and five for bottoms). The Model Initialization routine places these transactions at stations throughout the system. This routine also tags the transactions with parameters indicating pallet type and pallet status (empty at start of the model).

2. Block #2 - Load Raw Parts

    The function of the Part Loading routine is to place raw parts (bottom sides) on pallets. This is accomplished in the model by setting the status parameter associated with the transaction representing the pallet to one. Also, at this time the destination parameter associated with the transaction is set for the first machining operation associated with the part. The transaction is then moved to the queuing point for the 7" HBM's. (Block #3)

3. Blocks #3, 5, 6, 9, 11, 12, 13, 14, 19, 21 and 22 - Conveyor Moves (Front)

    The Conveyor Move (Front) routine transports pallets along the front side of the conveyor line (side adjacent to machines). This routine accomplishes conveyor motion by incrementing the initial conveyor location parameter associated with the transaction under consideration until it equals the destination parameter of the transaction. This routine will only accept conveyor movements of greater than one station.

4. Block #4 - <u>7" HBM Selection</u>

This routine determines which 7" HBM a pallet will be routed to for its next operation. This decision is based on conveyor line congestion and machine availability (next machine done with machining).

5. Blocks #7 and #8 - <u>7" Horizontal Boring Machines</u>

This routine simulates the machining activities associated with the 7" HBM's as well as the pallet motion required to move the part on and off them.

a. The shuttle mechanism removes pallet from conveyor line.

b. The 7" HBM is captured and machining begins.

c. The machining time elapses and the machine is released.

d. The shuttle mechanism returns the pallet to the conveyor line.

e. The shuttle is released and the part is moved to the queuing point for the next operation, station #5. (Block #9)

This routine also gathers appropriate statistics about pallet waiting times. After the machining operation occurs, a parameter associated with the transaction (pallet) being processed is set for the next operation.

6. Block #9 - <u>6" HBM Selection</u>

This routine determines which 6" HBM will be chosen to perform the next operation for the pallet under consideration. This decision is based on current conveyor line congestion (parts queued for machines) and machine availability (next machine done).

7. Blocks #15, 16, 17 and 18 - <u>6" Horizontal Boring Machines</u>

This routine simulates machining operations and pallet positioning associated with processing of a particular pallet. The important events in this routine are as follows:

a. The shuttle mechanism removes the pallet from the conveyor line.

b. The 6" HBM is captured and machining begins.

c. The machining time elapses and the 6" HBM is released.

d. The shuttle mechanism returns the pallet to the conveyor line and the pallet is sent to the queuing point for the next operation, station #13. (Block #19)

7. (Continued)

This routine gathers statistics with regard to pallet waiting time at the 6" HBM. Also a parameter associated with the transaction (pallet) is set to indicate the next operation to be performed.

8. Block #20 - <u>Selection of Boring Machine or Unload Station</u>

The choice between the Boring Machine (followed by part unload and loading of pallet with a half finished part) and the Unload Station is based exclusively on pallet type. Top pallets are routed to the Unload Station and bottom pallets are routed to the Boring Machine.

9. Block #21 - <u>Boring Machine</u>

This routine simulates the machining operations of the Boring Machine and associated pallet motions. The important events in this routine are as follows:

a. The shuttle mechanism removes the pallet from the conveyor line and propels it down the runway to the boring machine.

b. The boring machine is captured and machining commences.

c. Machining time elapses and the machine is released.

d. The shuttle mechanism moves the pallet back down the runway to the boring machine. The pallet is then sent to station #15 to wait for the unload station to become available.

10. Block #23 and 25 - <u>Unload of Finished Parts and Reload of Half Finished Parts</u>

Loaded bottom pallets arriving at the Unload/Reload Station have the finished part aboard them removed. Then the empty pallet is loaded with a half finished part moved from inventory. If no half finished part is available from inventory, the empty pallet is circulated at this end of the line until a part is available. The circulation path is typically through stations #16, 17, 18, 19, 20, 12, 13, 14 and 15. Note that circulation of pallets in this manner contributes significantly to system congestion. Before the pallet is ejected to Station #16, its parameters are set to indicate whether it is loaded or empty. If the pallet is loaded, 7" HBM #2 (Block #27) is set as its next destination. If the pallet is empty, Station #15 is set as its next destination.

11. Block #24 - Unload of Half Finished Parts

Loaded top pallets arriving at the Unload/Reload station have the half finished parts aboard them removed. The pallets are then flagged as empty and sent to the Load Station (Block #26). Parts removed from these pallets are entered into inventory.

MODEL VALIDATION

Whenever a complex model of a system is devised, the question of whether there is a correspondence between the model and the physical system invariably comes up. The best method to check the correspondence between the model and the real world system is to compare the results of the model with that of the system in a given situation. When modeling the initial system design of a Computerized Manufacturing System, it is obviously impossible to utilize the above method to check the validity of the model. Thus less straightforward methods of model validation must be utilized.

Several methods were employed to confirm that the model of the Computerized Manufacturing System developed in GPSS corresponds to the actual system design. The following are the methods utilized:

1. Manual Check of Model Flow Diagrams

The model flow diagrams once developed were evaluated on a block-by-block basis to check that they were analogous to occurrences in the physical system. Transactions (corresponding to pallets) were traced through the model to determine that the status changes of their parameters and their movements through the model were analogous to occurrences in the physical system. Once their validation was completed and resulting revisions made, the model flow diagrams were coded into a GPSS program.

The GPSS program was repeatedly checked against the model flow diagram to insure that all diagram blocks were included and properly translated.

2. Analysis of Current and Future Events Chains

Once an error free run of the model was obtained, the GPSS V print block was utilized to obtain listings of the block counts, current events chain, and future events chains at various time intervals during the simulation run. This data was then utilized to validate that transactions were moving through the model as desired and as anticipated. Where problems with transaction processing were discovered, the program was modified to eliminate these problems while maintaining model integrity.

3. Generation and Evaluation of Part Flow Diagrams

During the detailed evaluation of the current and future events chains, it became obvious

3. (Continued)

that there had to be a simpler method to confirm that the model was operating properly. While detailed evaluation of the current and future events chains was necessary for initial model validation, it seemed to be overkill for validation of minor model changes.

In order to provide a simpler method of confirming that the model was operating properly, GPSS V half word SAVEVALUES were added to record the position of pallets in the model (on the manufacturing line) at each moment of simulated time. A byte parameter was added to the transactions representing pallets to identify them (pallets 1-10); this parameter was used as an index for the appropriate SAVEVALUE. When a pallet entered a station, the station number was entered into the appropriate SAVEVALUE. Thus, at each moment of simulated time, these SAVEVALUES contain a snapshot of the manufacturing system. By printing these half word SAVEVALUES representing pallet positions in the system and the full word SAVEVALUES representing the time of completion of the machining operations at specific time intervals, the part flow diagrams shown in figures #5 and 6 can be constructed.

These flow diagrams have proved to be a powerful tool for model verification. They enable the system designer to obtain a feel for the way the system operates as well as identify system bottlenecks and congestion. Consideration has been given to using this data to construct a CRT display of the system operating in simulated time. In order to accomplish this, the capabilities of the help block could be used to extract this data while the model is running and place it in a separate disk file for future use. A separate program could then display this data in the appropriate form on a CRT terminal. This would enable the system designer to view a dynamic display of system operation. This potential enhancement of the model has not yet been made.

MODEL RESULTS

The basic purpose for modeling a Computerized Manufacturing System is to determine the production rate of a given Manufacturing System design. Having done this, it is possible to make modifications in the system design and observe the effect on the production rate.

In the following sections, various aspects of the Computerized Manufacturing System design simulated via GPSS V will be analyzed. Aspects of the Manufacturing System such as number of machines and topography of the system are not subject to change and therefore will not be investigated. Aspects of the system which will be investigated through GPSS simulation are as follows:

1. Production rate attainable with the basic system design.
2. Production rate attainable with stops for pallets at every station in the system.
3. Production rates attainable with the number of pallets in the system increased.
4. Production rates attainable with one or more machines in the basic system down.

1. Production Rate of Basic System Design

In the following paragraphs, results obtained from the GPSS V model were compared to the following analyses of system productivity:

- Manual calculations of systems production capability.
- CAN-Q queuing model productivity estimates.

a. Manual Calculation of System Productivity

Since the overall system productivity will be determined by the system component with lowest productivity and since the 7" HBM's and 6" HBM's were the machines with the highest utilization, all other machines are omitted from this analysis. Two productivity calculations were done for each group of machines. The first calculation was the achievable rate of production for the machines if they were constantly utilized. The second rate of production was that which could be achieved if a part was always queued for every machine in the group. This calculation uses the machining time plus the minimum transport time per part (two shuttle transport times + transport from queue to machine + transport time from machine to next station). Following are the calculations of these productivity rates. Note the machining times given in Figure #3 were the basis for these calculations.

7" HBM Productivity Maximum

7" HBM machining time/finished part = 37.5 min/part.
Milling time available/hour = 120 min.
Max. productivity = $\frac{120}{37.7}$ = 3.2 parts/hr.

7" HBM Productivity Maximum with Minimum Transport Time

7" HBM machining time + minimum transport time = 37.5 + 10.0 = 47.5 min/part.
Max. productivity with minimum transport time = $\frac{120}{47.5}$ = 2.52 parts/hr.

1. (Continued)

a. (Continued)

6" HBM Productivity Maximum

6" HBM machining time/finished part = 99.14 min. Drilling time available/hr. = 240 min.
Max. productivity = $\frac{240}{99.14}$ = 2.42 parts/hr.

6" HBM Productivity Maximum with Minimum Transport Time

6" HBM machining time/finished part + minimum transport time = 99.14 + 10.0 = 109.14 min.

*Maximum productivity with minimum transport time = 240/109.14 = 2.2 parts/hr.

*Note this is the upper limit of system productivity.

b. CAN-Q Model Productivity Calculations

Next the Computer Analysis of Networks and Queues (CAN-Q) program was utilized to determine the production rate for the system design. The mathematical modeling program (written in ANSI Standard Fortran) was obtained from J. J. Solberg of Purdue University. (20, 21) The input and output portions of the model were modified slightly for use on the PDP-11. The CAN-Q mathematical model reportedly yields accurate results for Computerized Manufacturing Systems although certain simplifying assumptions are made, such as steady state operation and that no blocking (material handling system congestion) occurs in the system.

For the purpose of the CAN-Q model, the machining operations done on the bottom and the top of the workpiece were considered to be two separate parts; as a result, the overall production rate given by the model was divided by two. The machining times utilized in the model were obtained from Figure #3. The transport time used in the model was the average transport time per machining operation and was calculated using the same transport times used in the GPSS model. The most significant results of the CAN-Q model are as follows:

Production rate = 1.87 parts/hr.
Maximum production rate = 2.2 parts/hr.
(Assumes greater than or equal to 15 pallets in system)

c. GPSS V Simulation Results

The GPSS V model provides data on the impact of detailed design decisions on system productivity and flexibility.

1. (Continued)

c. (Continued)

This data is significant to the designers as a measure of the effectiveness of the system design in its utilization of the machines in the system. This data is also of interest to potential customers as an indication of the flexibility of the design and as data for capital expenditure justification.

The GPSS V model yielded a production rate during steady state operation (steady state achieved after 16 hours) of 2.05 parts per hour. The production rates during the first two 8-hour periods were 1.5 parts/hr. and 2.12 parts/hr. respectively. The average machine utilization of the 7" HBM's and the 6" HBM's during steady state operation was 84.6% and 96.87%, respectively. The system bottleneck during steady state operation was the 6" HBM's.

The GPSS model yielded a higher production rate than the CAN-Q simulation of this model. This would seem to indicate that conveyor line congestion was not a significant problem in this system. This conclusion is consistent with the results of a detailed analysis of the part flow diagrams for this model. It is not too startling that the generalized CAN-Q model yielded results within 8% of the detailed simulation. In the paper entitled "Queuing Network Models for Computerized Manufacturing Systems" J. J. Solberg indicates that while no apriori model validation for CAN-Q can be done, the model yielded results surprisingly close to more sophisticated models (21). This statement is certainly consistent with the results obtained thus far. The results summarized below indicate that the results yielded by the GPSS V simulation are sensible.

Summary of Model Results

Manual calculation	2.2 parts/hr.
CAN-Q model with 10 pallets	1.87 parts/hr.
CAN-Q model asymptotical rate	2.2 parts/hr.
GPSS V simulation	2.05 parts/hr.

2. Production Rate of System with Stops at Every Conveyor Station

The basic system model was modified to include pallet stops at every conveyor station in the system. It was anticipated that this system modification would increase system flexibility, specifically the ability of the system to cope with congestion on

2. (Continued)

the conveyor system; and reduce the average production time lost due to pallet travel time. The results for this simulation are given below:

Revised System Model Results

Steady state production	2.18 parts/hr.
7" HBM utilization	82.6%
6" HBM utilization	97.5%

The above results indicate that a 7.9% increase in productivity could be achieved by placing stops at all conveyor stations in the system. It seems reasonable to expect that the increased productivity resulting from the higher system flexibility achieved by added pallet stops would be more evident if conveyor line congestion were more of a problem. This will be investigated in the following section by placing more pallets in the system.

3. Production Rate of System with Pallets Added

Both the basic system design and the revised system design (design with added pallet stops) were simulated with the number of pallets increased from 10. The results of these simulations are summarized below:

Model Results	# of Pallets	
	10	12
Basic system productivity (parts/hr.)	2.05	2.09
Revised system productivity (parts/hr.)	2.18	2.22

Note that the productivity increase resulting from the addition of two pallets to the system is the same for both the basic and revised system. This is a result of the fact that congestion on the transporter is not a significant problem for either system with 12 pallets. Where adding pallets results in significantly increased transporter congestion productivity will level off or fall. This point has not yet been reached for either system.

The above simulation indicates by adding two pallets to the system and stops at each conveyor station the system productivity could be increased by .22 parts/hr. The decision with regard to whether these system improvements should be made are dictated by the economics of the situation. The economic evaluation of the added capital expenditure is not treated in this paper.

4. Production Rates Attainable with Machines Down

Next the ability of the manufacturing system to produce parts with one or more machines in the system inoperative was investigated. One of the primary selling points of Computerized

4. (Continued)

Manufacturing Systems is their flexibility, by investigating the ability of the system to produce parts with less than a full complement of machines we hope to get an indication of system flexibility.

Simulation of System with Machines Down

	GPSS	CAN-Q
One 6" HBM inoperative	1.6 parts/hr.	1.48 parts/hr.
One 7" HBM inoperative		1.26 parts/hr.
One 6" HBM and one 7" HBM inoperative	1.3 parts/hr.	1.22 parts/hr.

The above results indicate that the machining system incorporates sufficient flexibility to allow it to achieve a reasonable level of production with one or more of its machines inoperable.

5. Other Results

Due to time limitations and since many of the design decisions for the system under evaluation were already made, a full factorial analysis was not conducted for this manufacturing system. Following are some of these areas where detailed analysis was deferred and some of the reasons for the deferral.

a. Routing Strategy - The obvious method of part routing is to route pallets to station closest to, but clear of, the destination machine, if possible, prior to the completion of the previous machining operation on the destination machine. Early simulations bore out this conclusion.

b. Speed of the Pallet Transporter - Consideration was given to investigating the effect of transporter speed on system productivity. However, the CAN-Q model output indicated that transporter was not a bottleneck and, as a result, the system was insensitive to it.

SUMMARY

The GPSS V modeling program has proved to be a valuable tool for the study of design alternatives for Computerized Manufacturing Systems. This program enables the system analyst to test the performance of a specific design in great detail. Although the investment in labor and computer time for GPSS V is considerably larger than that for less detailed modeling techniques, such as CAN-Q, the potential payback in higher system productivity and lower system cost make it an attractive investment.

The investigations described in the preceding sections have resulted in a two-fold approach to system modeling. The Computer Analysis of Networks and Queues program is used during the early stages of system design prior to the identification of a preferred system configuration. Once a preferred system configuration has been identified, a detailed GPSS V system model is constructed to allow evaluation of intricate design tradeoffs and to confirm productivity estimates obtained from the CAN-Q analysis.

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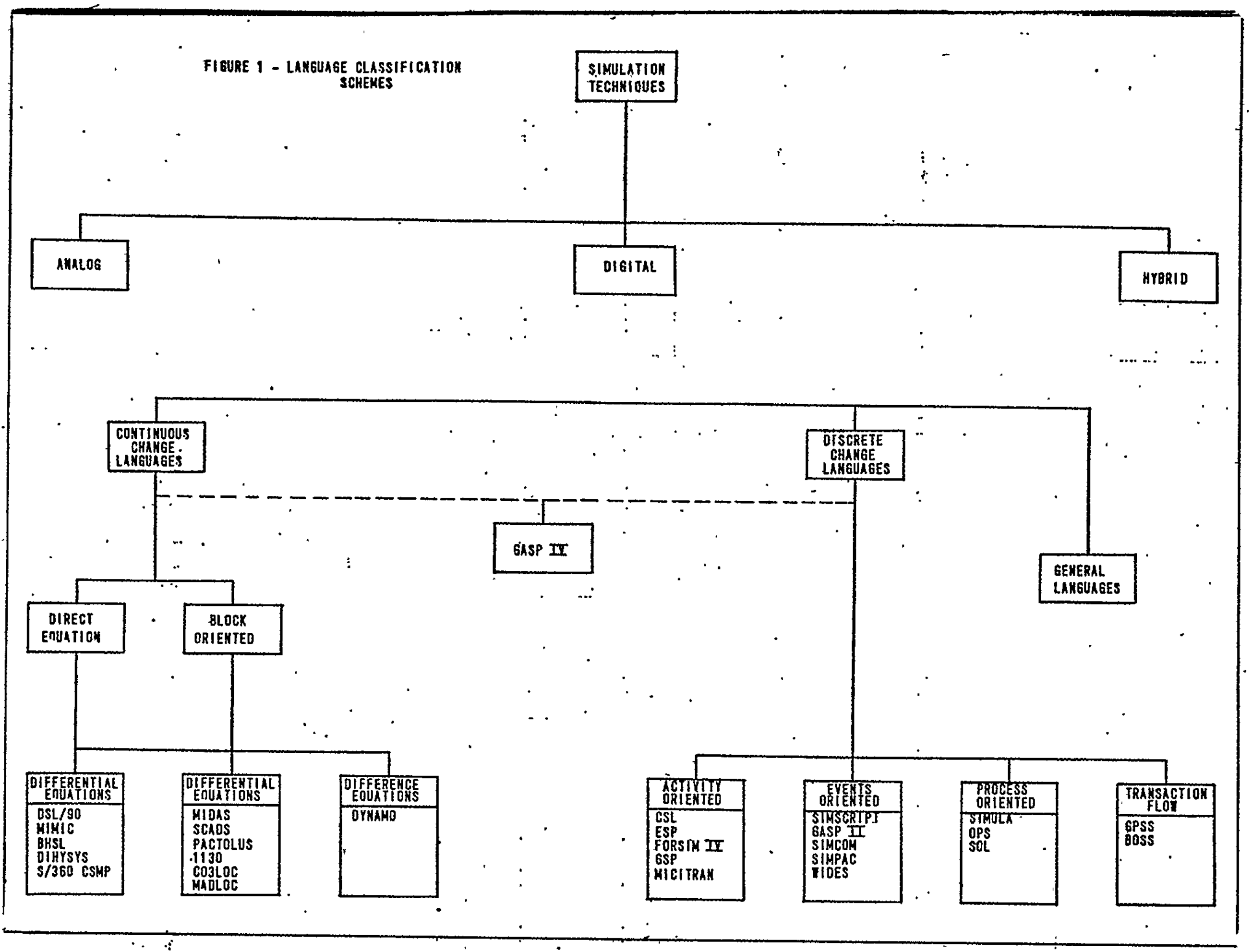
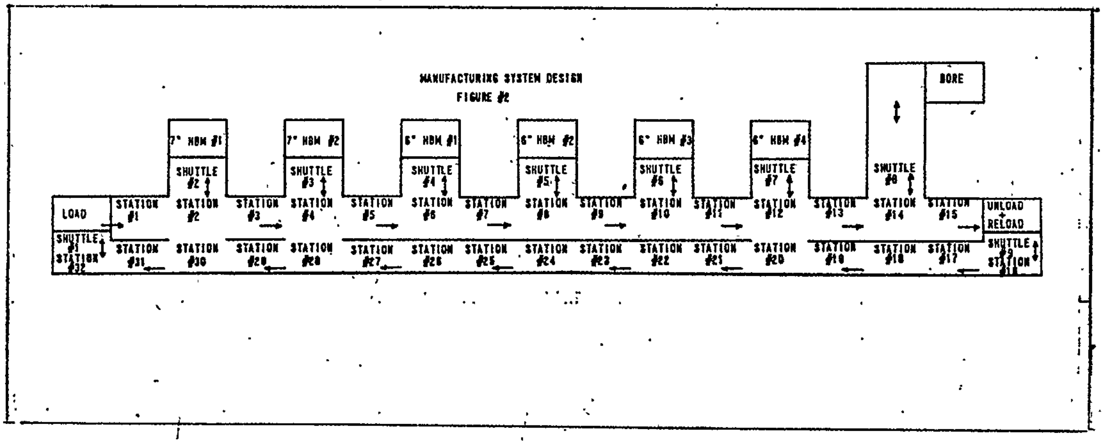


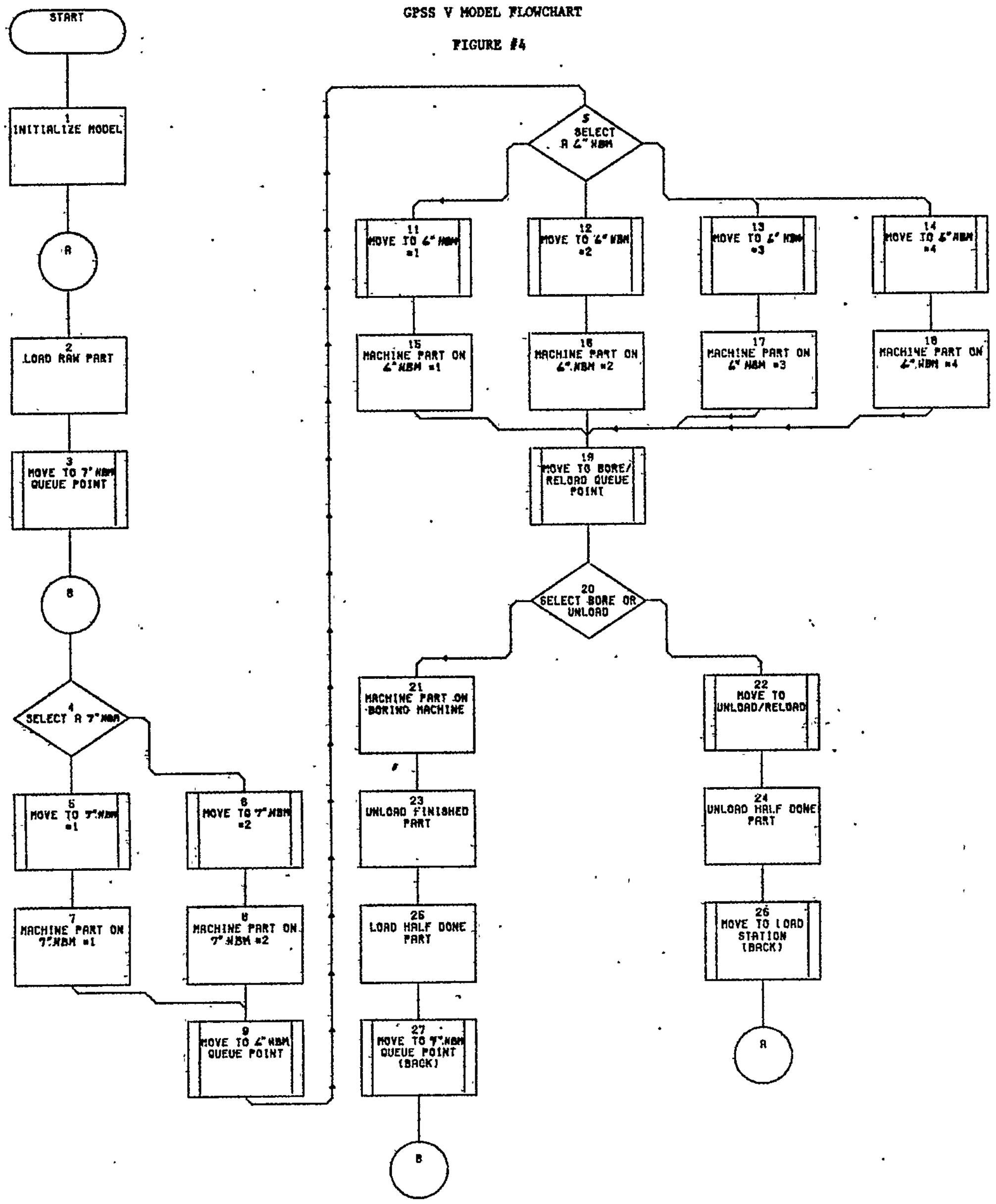
FIGURE 1 - LANGUAGE CLASSIFICATION SCHEMES


MANUFACTURING SYSTEM DESIGN
FIGURE #2

MACHINING SEQUENCE AND MACHINING TIMES

FIGURE 3

1.	Load workpiece onto bottom pallet	9.00 min.
2.	Mill bottom of workpiece (7" HBM)	19.11 min.
3.	Drill bottom of workpiece (6" HBM)	24.92 min.
4.	Bore bottom of workpiece	10.20 min.
5.	Unload bottom pallet	5.35 min.
6.	Load workpiece onto top pallet	6.20 min.
7.	Mill top of workpiece (7" HBM)	18.39 min.
8.	Drill top of workpiece (6" HBM)	69.72 min.
9.	Unload completed part	4.90 min.

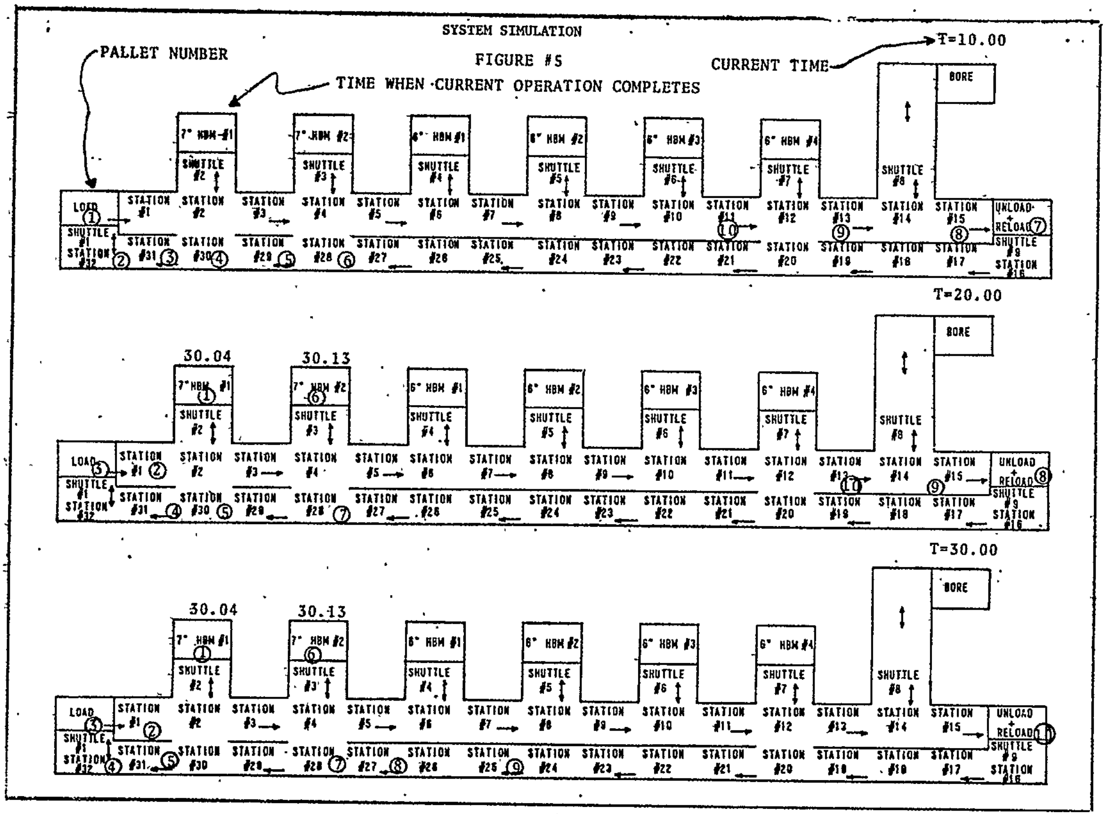


GPSS V MODEL FLOWCHART

FIGURE #4

SYSTEM SIMULATION

FIGURE #5



SYSTEM SIMULATION

FIGURE #6