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A microcomputer-based simulation model of a flexible manufacturing system with application to scheduling rules.

Thiruvengadam Ravi
University of Windsor

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A MICROCOMPUTER-BASED SIMULATION MODEL OF A FLEXIBLE MANUFACTURING SYSTEM WITH APPLICATION TO SCHEDULING RULES

by

Thiruvengadam Ravi

A Thesis submitted to the Faculty of Graduate Studies and Research through the Department of Industrial Engineering in Partial Fulfillment of the requirements for the Degree of Master of Applied Science at the University of Windsor

Windsor, Ontario, Canada

1987
UMI Number: EC54818

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To the one and only ????
This research deals with the development of a microcomputer-based simulation model of a Flexible Manufacturing System (FMS) using the general purpose simulation language SLAM (Simulation Language for Alternative Modeling). The FMS under consideration is composed of general purpose machining centers laid out in separate lanes, a loading and an unloading station, a central parts storage to store the raw materials and work-in-process parts, and automated material handling systems.

The simulation model which is adaptive to variations in the layout, serves as a decision tool to select a scheduling rule from amongst the five rules, namely, Random selection (RANDOM), Fewest Operations Remaining (FOPR), Most Operations Remaining (MOPR), Shortest Processing Time (SPT) and Longest Processing Time (LPT). The model includes realistic aspects such as, alternate routing for certain operations, treatment of fixtures as resources, and part types with priorities. The simulation model is user-interactive and does not require a prior working knowledge of SLAM.

Standard statistical techniques are used to select a scheduling rule from the five rules under...
consideration. An experimental design setup is used to aid the study of the effects of the different resources on the system performance. These procedures are illustrated through examples.
ACKNOWLEDGEMENTS

I would like to take this opportunity to express my gratitude to Dr. R. S. Lashkari and Dr. S. P. Dutta for their guidance and support during the entire course of this research. I would also like to thank Dr. R. J. Caron and Dr. P. Brill for reviewing my thesis and providing useful suggestions. A special note of thanks goes to Jacquie Mummery and Tom Williams for their invaluable help from time to time.

I wish to thank my friends, all the graduate students in the Department of Industrial Engineering, who have provided invaluable help through useful discussions.

Finally, I am very grateful to my parents, Dr. Thiruvengadam and Dr. Sulochana, for always being there when I needed them, in spite of the distance.
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CHAPTER I

INTRODUCTION

The fact that approximately 75% of the dollar volume of all metal-worked products are manufactured in lot sizes of less than fifty pieces each (Cook, 1975), spurred intensive research to develop a manufacturing system capable of producing mid-sized batches of a wide variety of parts efficiently. One important outcome of this research was the development of Flexible Manufacturing Systems (FMS) — systems capable of manufacturing mid-sized batches of a wide variety of parts with the efficiency of automated mass production systems and the flexibility of job shop systems. Referring to Fig.1, it can be seen that flexible manufacturing systems fit in between these two categories of manufacturing systems.

Rapid technological advances in the areas of numerically controlled machine tools (NC), automated material handling systems (MHS) and computer
Fig. 1 Comparison of various manufacturing systems

[Source: Groover & Zimmers (1984)]
communications have made flexible manufacturing systems possible. The high efficiency and productivity desired from such systems cannot be achieved, solely, by installing these highly sophisticated and expensive hardware. Due considerations should be given to the operational aspects, i.e., the software aspects, of these systems. This is essentially a complex managerial decision problem and at present is a major area of focus of researchers in the field of applied Operations Research.

This research deals with the development of a microcomputer-based simulation model of an FMS which can be used to address the operating problems. A brief introduction to the types of flexible manufacturing systems and the components that constitute an FMS is given in Chapter 2. The configuration of the FMS that has been considered for the development of the simulation model is also described in Chapter 2. In Chapter 3, the various problems posed by these systems and the modeling techniques that have been used in the past to address these problems are discussed. The objectives of this research are also presented in this chapter. The mode of operation of the FMS and the development of the simulation model on a microcomputer using SLAM (Simulation Language for Alternative Modeling) are discussed in Chapter 4. In Chapter 5, the application of the model to analyse
problems is illustrated through the use of three examples. The statistical technique for selecting a scheduling rule (policy) and the experimental design setup used to aid the study of the effects of important resources on the system performance are presented in the same chapter. Chapter 6 summarises the work done and provides some directions for further work that could be done to enhance the features of the model.
CHAPTER II

FLEXIBLE MANUFACTURING SYSTEMS

2.1 Definition and types of FMS

A flexible manufacturing system is described as "an automated batch manufacturing system that consists of a set of numerically controlled machine tools which are connected by automated material handling systems, all under the control of a central computer" (Groover & Zimmers, 1984).

Flexible manufacturing systems are broadly classified into two types (Browne & Rathmell, 1983), namely:

(i) Dedicated systems that are capable of processing a limited variety of parts in medium-sized batches;
(ii) Random systems that are capable of processing a larger variety of parts in small-sized batches.
2.2 Components of an FMS

An FMS consists of several components that interact with one another to achieve the goal of producing medium-sized or small-sized batches of a limited or larger variety of parts. The major components that constitute an FMS are:

(i) Numerically controlled machines
(ii) Automated material handling systems
(iii) Fixtures and pallets
(iv) Control computer(s).

Numerically controlled machines form the nucleus around which the whole system is built. These machines are capable of machining both rotational and non-rotational (prismatic) parts. More than 70% of the existing systems machine prismatic parts, while approximately 27% machine rotational parts and a few of them machine both types of parts (Bilalis & Manalis, 1985). These machines are equipped with servomotors that control the movement of the machine spindle and work table. Manual or programmed methods are used to generate electrical pulses from electronic controllers and these pulses in turn actuate the servomotors. Tool magazines that are capable of holding 100 to 150 cutting tools, e.g., drills, boring tools, reamers, milling cutters, taps, etc., are provided on these machines. An automatic tool interchanger
interfaces the machine spindle and the tool magazine. This device can interchange two cutting tools within a few seconds. Hence, as long as the required tool is in the tool magazine, the setup time required for interchanging the tools in between successive, but different processes is negligible. The introduction of a new part to be machined calls for a different set of cutting tools which can be set up quickly, thereby resulting in reduced setup times. This is not the case in conventional manufacturing systems.

Automated material handling systems are broadly classified as primary systems, e.g., tow carts, automatic guided vehicles (AGV’s) and conveyors; and secondary systems, e.g., shuttles. The primary systems transport the parts between the various stations, and the secondary systems transport the parts between the primary systems and the stations. The secondary systems also serve as storage areas for the parts at the machines, before and after machining, and are known as the input buffer and the output buffer, respectively. The purpose of the input buffer is to keep the machine busy, so that as soon as a part has been processed, the next part to be processed on the machine would be waiting in the input buffer. The part that has completed an operation on the machine is transferred to the output buffer where it waits for the unloading AGV. This essentially prevents the machined
part from waiting on the machine table, which would otherwise result in the machine remaining idle.

Fixtures are used to hold parts in a particular orientation to allow proper machining. A particular part type may require one or more fixture types. Furthermore, a part may be reoriented in the same fixture type for a different operation to be performed. In general, the part is clamped on to a fixture which is then bolted to a pallet. The whole unit is then mounted on a loading AGV which transports it to the appropriate machine. All the pallets used in a particular system are identical (Hartley, 1984). Thus, irrespective of the part type or the fixture type, any pallet can be loaded on to any AGV or machine table.

The coordination of all the activities of an FMS is under the control of a central computer or a group of computers. In situations where a group of computers are utilized, the computers are segregated into a hierarchy with proper communication links established between the different levels in the hierarchy. Some of the important functions performed by the computers include:

- production control
- traffic control
- loading part programs
- tool control
- system performance monitoring and reporting.
Most systems are provided with a central part storage area to store raw material and work-in-process parts. The capacity of this storage place is quite large and vertical space is made use of to compensate for restrictions in the floor space. Cutting tools are stored in a tool crib (central tool storage) and are sent to the appropriate machines as and when required. Loading stations, where the parts are clamped on to the fixtures and pallets, and unloading stations, where the parts are dismantled from the fixtures and pallets, form an integral part of any FMS.

2.3 Configuration of the proposed FMS

From the basic description of an FMS given in Section 2.2, it is possible to have several manufacturing facilities referred to as ‘FMS’. Therefore, it is important to define the configuration of the FMS assumed for the development of the simulation model.

Referring to Fig.2, it can be seen that the FMS consists of ‘L’ lanes (k=1,2,......,L), each lane containing a certain number of machines. Thus, there are $N_1$ machines in Lane 1, $N_2$ machines in Lane 2, $N_k$ machines in Lane k, and so on. The total number of machines, $M$, in the entire system is given by,

$$M = N_1 + N_2 + ..... + N_k + ..... + N_L$$
Fig. 2 Layout of the FMS with L lanes (L>1)
These M machines are general purpose Horizontal Machining Centers (HMC) or Vertical Machining Centers (VMC). In spite of their versatility, it is not always possible for these machines to perform all the operations, partly due to the technological constraints, for example, the size of the machine table, the accuracy of the machine, etc., and partly due to the type of operation itself, for example, a vertical machining center is more suitable for drilling or reaming operations than the horizontal machining center.

A central parts storage that stores raw materials as well as the work-in-process parts forms a part of the system. To compensate for restrictions in floor space a vertical storage racking system is assumed. Such a centralised storage system is referred to as an Automatic Storage and Retrieval System (AS/RS) and provides greater flexibility in terms of scheduling the parts into the system based on the different rules (Ranky, 1986).

Each machine in the system is provided with an input buffer and an output buffer, each having the capacity to hold one pallet. The parts that are selected to be processed are transported from the central parts storage to the loading station by means of a suitable material handling system, usually a crane or a fork-lift truck. At the loading station they are clamped on to the appropriate fixture and then bolted to the pallet. The
whole unit is then mounted on a loading AGV and transported to the respective machine. The parts that have completed an operation enter the unloading station where the entire unit consisting of the part, fixture, pallet and the unloading AGV is dismantled. A crane or a fork-lift truck transports the part from the unloading station to the central parts storage. The loading and unloading stations are manned. Hence, the assembling and dismantling operations are done by human operators.

Transportation of the parts from the loading station to the machines is done by one or more loading AGV's, while transportation of the parts from the machines to the unloading station is done by one or more unloading AGV's. Each lane is provided with a loading and unloading track on which the AGV's travel. The movement of the AGV's is controlled by the computer on a real time basis. The loading and the unloading track are laid out independently (Fig.2) and only one loading or unloading AGV is allowed to move on their respective tracks. This is done to prevent collisions and traffic congestions. A terminal at the loading station and another one at the unloading station provide information regarding the status of the loading or the unloading tracks. The loading and the unloading AGV's are not dispatched until the track on which they are to travel is clear.

The cutting tools are stored in the tool crib. A
suitable material handling system, such as an overhead tool conveyor that does not interfere with the AGV’s movements, transports the tools from the tool crib to the machines whenever a request for cutting tools is made. It is assumed that the requested cutting tools are always available at the tool crib.

The algorithm used to select the parts from the central parts storage and the algorithm that describes the flow of a part in the system are discussed respectively, in Section 4.1.1 and Section 4.2.2. The microcomputer-based simulation model was developed for the multi-lane type of FMS (Fig.2).
Flexible manufacturing systems are highly complex and dynamic in nature and hence pose a number of problems related to their design and operation. Stecke (1984) has identified problems which are frequently encountered once a decision to install an FMS has been taken. These problems are classified into four categories, namely:

(i) FMS design problems
(ii) FMS planning problems
(iii) FMS scheduling problems
(iv) FMS control problems

The first, second and fourth type of problems are often referred to as ‘static’ problems - the word static meaning one time allocation of the various resources; while the third type of problem is referred to as a ‘dynamic’ problem.
(i) FMS design problems

The FMS design problems are mainly concerned with the selection of the proper hardware. They include:

- selection of machines and equipment;
- determination of the various part types to be manufactured;
- determination of the layout of the machines, equipment, etc.

(ii) FMS planning problems

These involve certain decisions that are taken before the parts are loaded into the FMS for processing. They include:

- selection of a set of part types for immediate processing;
- the proportion at which the selected part types would be simultaneously processed in the FMS (part mix determination);
- the allocation of specific operations and tools to specific machines.

(iii) FMS scheduling problems

Scheduling is the allocation of jobs to be processed on specific machines and is classified as:

(a) Off-line scheduling - Using this approach a scheduling algorithm is applied at the beginning of the scheduling period, to result in a complete schedule for that period.
(b) On-line scheduling (dynamic scheduling) —

Using this approach the decision concerning the part to be processed next on a particular machine is made in real time at the termination of the operation currently being performed on that machine.

The FMS on-line scheduling problems are encountered when the system is operating and they include:

- determination of the next part to be processed on a machine;
- determination of alternate routing for a part.

(iv) FMS control problems

These are problems that arise with respect to keeping a constant check on the performance and quality standards of the machines. They include:

- design of preventive maintenance schedules for the machines and equipment;
- development of automatic inspection systems for parts and tools.

3.2 FMS models

A comprehensive review of the various techniques used to model flexible manufacturing systems have been provided by Wilhelm and Sarin (1983). These techniques are:

(i) Queueing network (analytical modeling)
(ii) Mathematical programming

(iii) Simulation.

Queueing network models have been based on the research initiated by Jackson (1957), in which network models were decomposed and analysed as a set of independent service stations. Based on the queueing network models of Baskett, et al. (1975) and the computer algorithms of Buzen (1973), Solberg (1977) developed a computer program (CAN-Q) to model an FMS. Buzacott and Shantikumar (1980) extended this methodology to study the part selection problem and evaluate alternative plans for work-in-process inventory. These network models, which provide the researchers with average performance measures of the system, have been applied mainly to solve the planning problems of an FMS. Realistic modeling of an FMS using this approach is severely restricted because the existing models fail to incorporate the various realistic features of an FMS such as, limited buffer capacities at the workstations, complex server disciplines, etc.

Mathematical programming techniques, e.g., integer programming, have been applied in certain static decision models. A set of 0-1 integer programming formulations were developed to evaluate the loading aspects of an FMS (Stecke, 1981). Kusiak (1983) proposed a few integer programming formulations of the loading problems. An optimization approach to determine the
optimal part routing policy for an FMS has been proposed by Kimemia & Gershwin (1985). Shanker and Tzen (1985) developed a mathematical model to study the loading and dispatching problems of a randomly generated FMS. Solutions from this mathematical model were used as inputs to a simulation model.

Though mathematical programming techniques are attractive in terms of their application to solve static problems of small and medium size, their application to large sized problems is restricted. This is due to the large formulations that are difficult to solve with the existing IP algorithms and packages. Moreover, certain constraints that are characteristic of an FMS (for example, tooling constraints) are difficult to consider due to the complexity involved in the formulations.

Simulation models have had the widest scope of application, partly due to the paucity of other types of models, and partly due to their ability to incorporate the realistic features of an FMS. Simulation is more suited for investigating the operational aspects of these complex manufacturing systems (Law, 1986). Stecke and Solberg (1981) explored alternative loading and scheduling strategies for the system installed at the Caterpillar Tractor Company. Due to the complexity of the various system aspects, analytical treatment was not viable and simulation was resorted to. Of the sixteen priority rules

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that were investigated, the weighted shortest processing
time was found to produce the best results for this system
in terms of the number of completed parts. Though the
results from this study cannot be extrapolated to other
systems that have different configurations and process
different part types, it demonstrated the usefulness of
simulation in evaluating different scheduling strategies.
ElMaraghy (1982) developed a special simulator called
FMSSIM (Flexible Manufacturing Simulator) to analyse
flexible manufacturing systems during their design phase.
The simulation model was made flexible enough to permit
variations in the quantities of the various resources used
by the system. The model served as a decision tool in
deciding the quantities of the different resources for
various systems processing different part types.

Parallel to the mathematical modeling of the FMS
installed at the SCAMP Systems Ltd, Rathmell, et al.
(1983) developed a simulation model to provide a detailed
investigation of the material handling, conveying and
overall workflow aspects of the system. Acree (1983)
studied various part, tool, and cart scheduling rules for
a system that was installed by the military. One of the
important findings of this study was the superiority of
individual tool allocation to the machines as and when
they are needed, as opposed to total tool allocation.
This study was system specific and since it was done for
the military, very little information has been made available to the public.

Carrie, et al. (1984) used a simulation model to analyse the sensitivity of system performance to variations in part mix, operation times and facility reliability for the system installed at Anderson Strathclyde, Scotland. Wortman and Miner (1984) developed MAP/1, a simulator specifically designed for modeling discrete manufacturing systems. Using this simulator they evaluated an FMS design in which the variables analysed were the number of dedicated and flexible machines and the number of fixtures and carts. Another application of the MAP/1 simulator was in deciding the number of fixtures for a machine tool manufacturer. Chang, et al. (1986) used the general purpose simulation language, SLAM (Pritsker, 1984), to design the material handling system of an FMS. This study demonstrated the flexibility of SLAM as compared to that of Q-GERT (Pritsker, 1977) or GPSS (Schriber, 1974), in terms of the modeling and output analysis.

Since an FMS consists machines which are flexible enough to perform a wide variety of operations, certain operations on certain part types could be processed by different machines. This gives rise to the concept of alternate routings. However, this inherent feature of an FMS, has not been treated by the simulation models.
appearing in the literature.

The efficient operation of an FMS is dependent, to a certain extent, on the availability of the various resources like pallets, carts, human operators, etc. Though a major portion of the work carried out so far has dealt with the issue of deciding the number of pallets or carts and the allocation of these resources to different parts, there has been no report of any work that has considered the fixtures as a constraining resource. With a considerable increase in the number of random systems, which machine a larger variety of parts as compared to dedicated systems, the use of standardised pallets to hold the parts in proper orientation for the machining to be performed is extremely difficult. This has led to the development of fixtures to interface the part and the pallet. These fixtures are expensive due to the precision machining involved and are available in limited quantities. Even with a considerable increase in the use of modular fixtures, which are assembled from standard components (Drake, 1984), the availability of these standard components result in a limited quantity of the fixtures. Moreover, a part that has been selected to enter the system would be prevented from doing so unless the required fixture type is available, in spite of the availability of the other shared resources like pallets and the AGV’s. Hence, fixtures are important resources.
and should be considered during the development of the model.

In dedicated flexible manufacturing systems the variety of parts being processed is small and the batch sizes of the various part types are large enough to maintain a constant number of parts of each type as long as the set of part types remain unchanged. Much research has been done in the past to formulate models that determine the proper part mix — the proportion of the various part types in the system — to be maintained in the system at all times. The part mix determination problem controls the scheduling of parts into the system, since a part that leaves the system is always replaced by another one of the same type, to maintain the same proportion.

However, as mentioned earlier, with a considerable increase in the number of random systems that are capable of processing a larger variety of parts in smaller batch sizes (say, 5 or less), the determination of a suitable part mix is highly inappropriate. Such systems are similar to the typical job shop systems in which batch sizes of one are not uncommon and the scheduling of parts into the system has to be based on some criterion. The complex nature of these systems rule out the possibility of the development of off-line scheduling algorithms to input parts into the system. Moreover, inclusion of the realistic features, e.g., alternate routings, etc.
complicate these off-line algorithms. On-line scheduling, or dynamic scheduling, which essentially depends on the state of the system, is more suited to such systems. The complexities involved in the development of the queueing network and mathematical models to address the problem of on-line scheduling along with the consideration of the realistic features such as, alternate routing and the treatment of fixtures as resources, justify the use of a simulation approach.

3.3 Objectives of the research

This research deals with the development of a simulation model of the FMS described in Sec 2.3 which can be used as a decision tool to select a scheduling rule from the five rules under consideration.

Five simple priority scheduling rules considered in this thesis, based on the part characteristics, are:

(i) Random selection rule (RANDOM)
(ii) Fewest operations remaining (FOPR) rule
(iii) Most operations remaining (MOPR) rule
(iv) Shortest processing time (SPT) rule
(v) Longest processing time (LPT) rule

The simulation model which would incorporate features such as, alternate routings, treatment of fixtures as resources and part types with priorities, is to be developed on the
microcomputer using the general purpose simulation language, SLAM. The simulation model is to be user-interactive so that it does not require a prior working knowledge of SLAM. This front-end interface between the user and the computer is to provide flexibility in using the model.
CHAPTER IV

SIMULATION MODEL OF THE FMS

The development of the simulation model of the FMS under consideration is discussed in this chapter. The operation of the FMS, namely, the part-machine selection algorithm and the flow of the part in the system is explained in Section 4.1.1 and Section 4.1.2, respectively. The development of the different computer programs which together form the simulation model of the FMS is explained in Section 4.2. In Section 4.3 the techniques that were used to verify the model are outlined.

4.1 Mode of operation of the FMS

The conversion of a part type from the raw material state (generally, castings or forgings) to a fully machined product involves a series of processing steps. These processing steps are generally combined into
one or more operations. Each operation requires one or more specific cutting tools. The procedure of combining these processing steps into operations is usually done by an experienced process planner and a certain degree of objectivity is involved.

As an example, the development of the operations sheet for the sample prismatic part shown in Fig. 3 is given below.

<table>
<thead>
<tr>
<th>Processing steps</th>
<th>Cutting tools</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. ROUGH MILL BOTTOM FACE</td>
<td>FACE MILLING CUTTER (M1)</td>
</tr>
<tr>
<td>2. FINISH MILL BOTTOM FACE</td>
<td>FACE MILLING CUTTER (M2)</td>
</tr>
<tr>
<td>3. ROUGH MILL TOP FACE</td>
<td>FACE MILLING CUTTER (M1)</td>
</tr>
<tr>
<td>4. FINISH MILL TOP FACE</td>
<td>FACE MILLING CUTTER (M2)</td>
</tr>
<tr>
<td>5. MILL DOVETAIL SLOT</td>
<td>SPECIAL CARBIDE TIPPED MILLING CUTTER (M3)</td>
</tr>
<tr>
<td>6. DRILL CENTER HOLE (10mm)</td>
<td>DRILL - 10mm DIA (D1)</td>
</tr>
<tr>
<td>7. ENLARGE CENTER HOLE to 20mm</td>
<td>DRILL - 25mm DIA (D2)</td>
</tr>
<tr>
<td>8. REAM CENTER HOLE (20mm)</td>
<td>REAM - 20mm DIA (R1)</td>
</tr>
<tr>
<td>9. ROUGH BORE CENTER HOLE</td>
<td>BORING TOOL (B1)</td>
</tr>
<tr>
<td>10. FINISH BORE CENTER HOLE</td>
<td>BORING TOOL (B2)</td>
</tr>
</tbody>
</table>

These processing steps can be combined into two different sets of operations as shown below.

<table>
<thead>
<tr>
<th>Operation set # 1</th>
<th>Operation set # 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation # 1 : Steps 1,2</td>
<td>Operation # 1 : Steps 1,2</td>
</tr>
<tr>
<td>Operation # 2 : Steps 3,4,5</td>
<td>Operation # 2 : Steps 3,4</td>
</tr>
<tr>
<td>Operation # 3 : Steps 6,7,8</td>
<td>Operation # 3 : Steps 5</td>
</tr>
<tr>
<td>Operation # 4 : Steps 9,10</td>
<td>Operation # 4 : Steps 6,7,8</td>
</tr>
<tr>
<td></td>
<td>Operation # 5 : Steps 9,10</td>
</tr>
</tbody>
</table>

In this model it is assumed that each operation on a part type is done in a single setup on a machine. After the completion of an operation, a part returns to be refictured or reoriented in the same fixture for the next
Fig. 3 Sample prismatic part
operation. Hence, the number of visits made by a part into the system is equal to the number of operations to be performed on it.

The mode of operation of the FMS under consideration is explained by dividing it into two stages. The first stage deals with the selection of a part from the parts in the central parts storage based on the scheduling rule that is followed. The second stage deals with the actual flow of the selected part in the system.

4.1.1 Part-machine selection algorithm

Parts are selected from the central parts storage based on the scheduling rule being followed. Though this appears simple initially; due to the unavailability of the right fixture and machine(s) for the operation of the selected part, and the presence of parts that have priority over other parts, it is not always possible to adhere to the rule being followed. In order that the system is always loaded with parts, a compromise has to be made when the scheduled part cannot enter the system. The algorithm for selecting a part from the central parts storage under such conditions is explained below. This part-machine selection algorithm consists of a set of blocks, A through P. The flow chart of this algorithm is

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ALGORITHM:

(A) When the input buffer of a machine(s) becomes available, the central parts storage is requested to send a part for processing. Go to block (B).

(B) If all the parts in the central parts storage have been considered, then go to block (P), otherwise go to block (C).

(C) If there are parts in the central parts storage with priority then go to block (D), otherwise go to block (N).

(D) A set of parts that have priority over other parts is formed. Go to block (E).

(E) A part is selected from this set based on the scheduling rule being followed. This part is called as the candidate part. Go to block (F).

(F) The operation to be performed on this part type is noted and the availability of the fixture type for this operation is checked. If the fixture type is available, then go to block (G), otherwise go to block (K).

(G) If the candidate part could be processed on the machine(s) whose input buffers are empty, then go to block (H), otherwise go to block (K).

(H) If candidate part could be processed on more than one machine, then the machine whose total
distance from the loading and unloading stations is the smallest is selected to process the part.
Go to block (I).

(I) This candidate part is then sent to the selected machine for processing. Go to block (J).

(J) If there are any more input buffers that are empty, then go to block (A), otherwise go to block (P).

(K) This candidate part is removed from further consideration. Go to block (L).

(L) If there are any parts in the central parts storage with priority, then go to block (M), otherwise go to block (N).

(M) A new set of parts, excluding the candidate part, is formed from the set of parts that have priority over other parts. Go to block (E).

(N) If there are parts in the central parts storage without priority, then go to block (O), otherwise go to block (P).

(O) A set of parts without priority is formed. Go to block (E).

(P) The selection algorithm is stopped.

4.1.2 Part flow in the system

Based on the algorithm in Section 4.1.1, a part is
Fig. 4. Flow chart of part-machine selection algorithm.

A: The central parts storage is requested to send a part as soon as the input buffer becomes available.

B: Have all the parts in the central parts storage been considered?
   Yes → C
   No → A

C: Are all the parts in the CBS with priority?
   Yes → 2
   No → 1

1: Yes
2: No
3: No
4: Yes
Fig. 4 (continued)

1. A set of parts with priority over other parts is forwarded.
2. A set of parts, excluding the candidate part, that have priority over other parts is forwarded.
3. A set of parts without priority is forwarded.
4. Is the fixture type for the candidate part available?
   - Yes
   - No
5. Remove this candidate part from further consideration.
6. No
7. No
8. Yes

A set of parts in the central parts storage with priority?
   - Yes
   - No

A set of parts in the central parts storage without priority?
   - Yes
   - No
Fig. 4 (continued)
selected to be processed on a particular machine. The
flow of this selected part in the system is explained
below and the flow chart is shown in Fig.5.

ALGORITHM:

(i) The selected part waits in the central parts
storage until the loading crane, loader, loading
AGV and pallet are available. Once these
resources are available, go to step (ii).

(ii) The part is transported to the loading station
by the loading crane. At the loading station the
part is clamped in the appropriate fixture and
then bolted on to a pallet. The entire unit is
then mounted on a loading AGV.
This loading AGV is kept waiting at the loading
station until the loading track is clear. Once
it is clear, go to step (iii).

(iii) The unit is transported to the machine and then
transferred to the input buffer of the machine.
The unit is kept waiting in the input buffer
until the machine table is empty. Once it is
empty, go to step (iv).

(iv) The unit is transferred to the machine table. A
check is made to see if all the cutting tools
that are required for this operation are
available in the tool magazine.
A request is made to the tool crib to send the
necessary cutting tools that are not available. The processing on the parts is not started until all the cutting tools are available. Once all tools are available, go to step (v).

(v) The processing steps for the operation on the part are carried out. After the completion of the operation, the unit is kept waiting on the machine table until the output buffer of the machine is empty. Once it is available, go to step (vi).

(vi) The unit is transferred to the output buffer of the machine. The unit is kept waiting on the output buffer until the unloading crane, unloader and unloading AGV are available. Once these resources are available, go to step (vii).

(vii) The unloading AGV is kept waiting at the unloading station until the unloading track is clear. Once it is clear, go to step (viii).

(viii) The unloading AGV is then sent to the machine to pick up the unit and transport it to the unloading station. At the unloading station the unit is removed from the unloading AGV and dismantled. The part is then transported to the central parts storage by the unloading crane. Go to step (ix).

(ix) If all the operations on the part have been...
completed, then the part does not enter for further processing, otherwise the part stays in the central parts storage.

The travel times from the central parts storage to the loading station, from the loading station to the machines, from the machines to the unloading station, and from the unloading station to the central parts storage, are deterministic because of the use of automated material handling systems that result in constant times. The use numerically controlled machines results in processing times that are deterministic. However, the loading times at the loading and unloading stations are stochastic since the loading and unloading operations are performed by human operators. As a result of this, the time spent in waiting by the parts for the different resources and the machines are of a random nature. Hence, the output from the simulation model is stochastic.

4.2 Development of the simulation model

The simulation model of the proposed FMS, whose configuration was described in Section 2.3 and whose mode of operation was described in Section 4.1, was developed on an IBM/PC microcomputer using SLAM. SLAM is a general purpose simulation language that is used to develop computer models of discrete change or continuous change
Part selected for processing. Machine on which part is to be is also selected.

Are the loading crane, loader, loading AGV, and pallet available?

Yes

Keep part waiting in the central parts storage.

No

Part transported to the loading station by the loading crane where it is clamped to the fixture, then bolted to a pallet and the entire unit mounted on the loading AGV.

Is the loading track clear?

Yes

Keep part waiting in the loading station.

No
(iii) Unit transported to the machine and then transferred to the input buffer of the machine.

Is the machine empty?

Yes

No

Keep unit waiting in the input buffer.

(iv) Unit transferred on to the machine table.

Are all the cutting tools available?

No

The tool crib is requested to send the tools that are not available on the machine. Processing is not started until all the are available.

Yes

Fig. 5 (continued)
(v) Is the output buffer of the machine empty?
   Yes
   Start processing and stop after the prescribed time.
   No
   Keep part waiting on the machine table.

(vi) Part transferred to the output buffer of the machine.

Are the unloading crane, unloader, and unloading crane available?
   Yes
   Keep part waiting in the output buffer.
   No

Fig. 5 (continued)
Is the unloading track clear?

Yes

The unloading AGV is sent to the machine to pick up the unit and transport it to the unloading station where it is removed from the unloading AGV and dismantled. The part is then transported to the central parts storage by the unloading crane.

Are all the operations on part complete?

Yes

Part does not enter the system for further processing

No

Keep the part in the central parts storage.

Keep the unloading AGV at the unloading station.
Systems. The microcomputer version of SLAM is based on Microsoft Fortran (MS FORTRAN).

The FMS under consideration can be modeled as a discrete change system since the state variables that describe the system, e.g., the number of parts inside the system, the number of busy machines in the system, etc., change at discrete points in time. Discrete change systems are modeled in SLAM using one of the following three approaches (Pritsker, 1984):

(i) Process orientation (Network modeling)
(ii) Event orientation
(iii) Combined process—event orientation.

The combined process—event orientation approach was used to develop the simulation model of the proposed FMS. This approach combines the advantages of the process orientation and the event orientation approaches. Using this approach the entire system was modeled using a network model and at instances where increased flexibility is required, the event orientation approach was used.

The software that was written was divided into two major programs (Fig. 6), namely:

(i) Program 1 - This program creates the data files that are later accessed by the SLAM program as the simulation progresses.
(ii) Program 2 - This is the main simulation program written in SLAM. The program is further subdivided into
Fig. 6 Organisation of the computer program
two different modules, namely:

(i) SLAM discrete event program
(ii) SLAM network program.

4.2.1 Program 1 - Input data creation

For each part type, its priority, its batch size, the number of operations, the fixture type for each operation, the machine(s) on which each operation could be performed and the cutting tools required for each operation have to be provided as input data. Moreover, the number of machines in the system, the distances of these machines from the loading station, the unloading station and the tool crib, and the speed of the different material handling systems form part of the input data. As a result of this, it is a cumbersome procedure to input data whenever a scheduling rule is analysed or the resource levels are changed. In order to prevent this inconvenience to the user, the above data is stored in different data files which are later accessed by the simulation program. A user interactive program was written in Microsoft Advanced Basic (MS BASICA) which creates these different data files as the user responds to a series of queries during the execution of the program. This program is a menu driven program and consists of a set of subprograms that are used to:
(i) create new data files
(ii) review and alter existing data files
(iii) add details to the existing data files
(iv) print out the details of existing data files.

A computer listing of this program is given in Appendix-A.

4.2.2 Program 2 - SLAM simulation program

Since a combined network-discrete event modeling approach was followed, the simulation program in SLAM consists of two modules, namely:

(i) SLAM discrete event program
(ii) SLAM network program.

The SLAM network program is used as a driver program for the simulation. The flexibility in terms of the part-machine selection algorithms, the multiple resource allocation procedures and the automated material handling equipment travel times are provided by the SLAM discrete event program.

4.2.2.1 SLAM discrete event program

This program (Appendix-B) was written in MS FORTRAN since SLAM is a Fortran based simulation language. A modular approach was followed during the development of the program which resulted in the entire...
program being organised into a number of subroutines.

The input data that is required by the simulation program is loaded into the computer memory by the MAIN routine. This routine calls the SLAM execution processor to start the simulation. Commands that require the user to input the scheduling rule, the number of runs, the names of the files from which the input data has to be retrieved and the quantities of the various resources to be used, on an interactive basis, are contained in this routine (Appendix-C).

The subroutine (INTLC) initialises the simulation to the same initial conditions at the start of each run when multiple runs are used. Part selection based on the scheduling rule followed, checking the tools in the tool magazines of the machines, deciding the re-entry of a part into the system, collecting data on utilizations of the resources and the machines, and printing out the results are some of the important EVENT routines that are employed in the program. These routines are called when a part enters the corresponding EVENT node in the network.

Allocation of the multiple resources is handled by ALLOC(I) subroutine that is invoked as a part enters the AWAIT node in the network model. The USERF(I) subroutine returns the value of the travel times of the different material handling equipment when a part passes through the USERF branch.
4.2.2.2 SLAM network program

The network model of the FMS consists of the SLAM network symbols, namely, the nodes and branches. The program consists of statements that are classified as control statements and network statements. The control statements are used to control the number of simulation runs, to initialise the seeds at the start of each run, to store the entities in files based on certain priorities, to start and end the simulation, etc. The network statements represent the various nodes and branches used in the network model. The SLAM network program, whose listing is given in Appendix-D, consists of a number of segments as shown in Fig.7.

Segment 1 (Fig.8) - The CREATE node starts the simulation and the EVENT node (EVE1) selects the parts based on the rule being followed. The selected part waits for the following resources - the loading crane, loading AGV, loader and pallet - at the AWAIT node (MULT). Once these resources are available, they are allocated to the first part waiting at this node.

Segment 2 (Fig.9) - The transportation time from the parts storage to the unloading station is provided by the USERF routine (USERF(1)). The loading time at the...
loading station is represented as a service activity. Due to the stochastic nature of the loading activity, the loading time follows a probability distribution. Depending on the system under consideration and the distribution that is appropriate, the exact function that generates random variables for this distribution with the assumed parameters can be used in the corresponding network statement. After the unit has been mounted on the loading AGV, the loading crane and the loader are freed by the FREE nodes (FCRA and FLOA). The loading AGV waits in the AWAIT node (AW25) until the loading track on which it is to travel is clear. The ASSIGN node (AS20) increments the number of parts being processed (XX(20)) every time a part flows through this node. The travel time from the loading station to the machine is returned by the USERF routine (USERF(2)). At the machine the pallet is transferred from the loading AGV to the input buffer of the machine. This transfer time is very small and hence assumed to be zero. The travel time of the loading AGV from the machine back to the loading station is returned by USERF(3). The EVENT node (EVE2) releases the loading AGV and the loading track, i.e., it indicates that the loading track is clear, while EVENT 3 (EVE3) is used to check for the tools in the tool magazine of the machine and make a request to the tool crib to send the required tools that are not available in the tool magazine of the
Segment 3 (Fig.10) - The input buffers of the machines are represented as AWAIT nodes (BUF1 to BUF9). The machines are treated as resources and the part waits in the appropriate AWAIT node for the machine (as an example, BUF1 for machine 1). The capacity of each input buffer is set at one unit. The EVENT node (EVE4) is used to free an input buffer once the corresponding machine becomes available. It is also used to request the parts storage to send a part to this machine whose input buffer is empty. At the machine table, the part waits for the tools from the tool crib if they are not in the tool magazine of the machine. This waiting time is modeled as an activity, USERF(4), which returns the value of the waiting time. The SLAM variables, XX(11) to XX(19), represent the status of the machines. A value of 1 indicates that the respective machine is busy, while a value of 0 indicates that the machine is idle. This facilitates automatic collection of statistics on the utilization of the machines. The processing times on the machines are represented as activities (ACT 1 to ACT 9). After a part has been processed on a particular machine, the FREE node (FREM) sets the machine free. The output buffers at the machines are denoted by the QUEUE nodes (QU10 to QU18). These queues have a capacity of one unit.
each and they block any entities from entering when they are full, i.e., when there is a part already in the output buffer waiting for the unloading AGV.

Segment 4 (Fig.11) - The AWAIT node (AW23) is a dummy node in which a part waits until the unloader, unloading AGV and the unloading crane are free. USERF(5) returns the value of the travel time from the appropriate machine to the unloading station. The travel time for the unloading crane is returned by USERF(6). The unloading time to dismantle the entire unit at the unloading station is modeled as an activity. As in the case of the loading time, the unloading time is also stochastic and the same procedure is adopted to generate random variables that follow the specified distribution. Once the dismantling is over, the FREE nodes, namely FPAL, FULO, and FRUG, are used to free the pallet, the unloader and the unloading AGV. The EVENT node (EVE5) is a user written EVENT routine that releases the necessary fixture type and indicates that the unloading track is clear. The part is then transported to the parts storage. USERF(7) provides the value of the travel time elapsed. The FREE node (FUCR) releases the unloading crane at the central parts storage. The check as to whether a part that returns to the parts storage has finished all its operations or not is handled by the EVENT routine (EVE6). This routine also
collects the necessary data which are printed out at the end of the simulation.

Segment 5 (Fig. B) - This is an intermediate segment that requests the parts storage to select a part when one or more input buffers are empty. It triggers the EVENT routine (EVE1) when the GATE (CLO2) is opened and a dummy entity waiting in the AWAIT node (BAIN) is released.

Five different network programs, one for each rule, were written in SLAM. These programs are the same except for the PRIORITY statement. This is a SLAM control statement that is used to store the parts in the central parts storage according to the scheduling rule being followed. As a result of this, five different network programs, one for each rule, were written and compiled. The SLAM network program relating to the FOPR rule is listed in Appendix-D. During the execution of the program, depending on the rule (policy) to be followed, the user is requested to enter the name of the appropriate network program that has been compiled.

4.3 Model verification and validation

Verification is the process of determining whether the simulation model is performing as intended,
Fig. 9 Segment 2 of the SLAM network model
Fig. 10 Segment 3 of the SLAM network model

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Fig. 11 Segment 4 of the SLAM network model
i.e., debugging the computer program (Law & Kelton, 1982). The following techniques are generally used to debug computer programs of simulation models. These techniques include:

(i) the use of a modular approach to develop programs. However, this approach is dependent to a large extent on the language being used and many simulation languages have limitations in this regard.

(ii) the use of a trace in which the events that occur as the simulation progresses are printed out.

(iii) using results from analytical models that have already been developed for the system being simulated. In some cases by making certain simplifying assumptions, a suitable analytical model can be approximated. The results from the simulation model are then compared with those of the analytical model.

(iv) the use of animation that displays the simulation on the terminal as the simulation progresses. Presently a number of simulation softwares, for example, TESS, SIMAN, SEE- WHY, etc., that represent the system graphically on the terminal and display the changes that take place as the simulation progresses, are available.

The program that was written for simulating the
FMS contains thousands of lines of computer code. There exists no analytical model that is similar to the FMS under consideration. Verification of the system by equating it to an existing analytical model and comparing the results of both is out of consideration. Hence, the model was verified by tracing the program as the simulation progressed. At the user’s request for a trace of the simulation, the WRITE statements are activated and the various events that take place at discrete points in time are printed out. Using one or two of machines and a maximum of three part types, this procedure was followed for different number of combinations. From the printouts it was found that model was performing as intended. This was the main debugging tool used to verify the simulation model. A typical traced output that was used to verify the program is shown in Appendix-E.

Validation is the process of determining whether the simulation model is an accurate representation of the real world system. Complete validation for the FMS under consideration is extremely difficult due to the non-existence of such a system. Hence, the general validation procedure in which output from the simulation model is compared with the output from the real system for the same input details, is not possible with this system.
CHAPTER V

MODEL APPLICATION

In this chapter the application of the microcomputer-based simulation model is demonstrated through the use of three examples. Section 5.1 explains the statistical technique that is used to select a policy from the set of policies under consideration. The examples considered in Section 5.2 illustrate this selection technique. The factorial design set up that is used to aid the study of the effects of the important factors (resources) on system performance measure is explained in the same section.

5.1 Selection of the policy

The FMS under consideration processes different batches of part types during different periods. The system starts operating at time 0 with all the machines in an idle state and the raw materials for the entire set of
part types to be machined during the period made available in the central parts storage. The system stops operating when all the parts in the entire batch have been processed, thereby completing a cycle. The next batch of parts to be processed are introduced into the system and the system starts all over again for the next cycle. Thus the system is a terminating type of system that starts with certain initial conditions at a time \(0\) and terminates at a time \(T_E\) on the occurrence of event \(E\). Hence, statistical techniques that are generally applied to analyse output data for terminating simulations can be applied to this system.

Given all the necessary details of the FMS under consideration, i.e., the configuration, the part types to be processed and their details, the levels of the various resources that are available, etc., our objective is to select a scheduling rule (policy) from the five rules under consideration. The statistical procedure that is used for this purpose is based on the method developed by Dudewicz and Dalal (1975) for selecting a policy out of, say, \(k\) policies. The entire procedure is a comparison of alternate policies based on some criterion, namely, the system performance measure. The policy to be selected is the one that results in either a low or a high value of the system performance measure under consideration, as the case may be. For example, if makespan, which is defined as
the total time in system for the set of part types to be processed by the system, is chosen as the system performance measure, we would select the policy that results in the shortest makespan. However, if machine utilization, which is defined as the ratio of busy time of the machine to the total simulation time, is chosen as the system performance measure, we would select the policy that results in the highest machine utilization.

5.1.1 Notations used

\( X_{ij} \) - the random variable of interest (some measure of performance) from the \( j^{th} \) independent replication of the \( i^{th} \) policy, \( (i = 1,2,\ldots,k) \) and \( (j = 1,2\ldots,N) \)

\( k \) - number of policies under consideration

\( CS \) - the event of 'correct selection' of a policy

\( P(CS) \) - the probability of selecting the correct policy

\( \mu_i \) - the population mean of the random variable \( X_{ij} \) for the policy 'i'.

\( \mu_i = E(X_{ij}) \)

Depending on the measure used to evaluate the system performance, we would select the policy that
results in either the smallest expected response or the largest expected response. Let us assume that we are interested in selecting the policy that results in the smallest expected response.

Let \( \mu_{i\in n} \) be the 1st smallest of the \( \mu_i \)'s, such that:

\[
\mu_1 \leq \mu_2 \leq \cdots \leq \mu_k
\]

Our objective now is to select the policy with the smallest expected response, \( \mu_{i1} \). Since the output from a simulation model is of a stochastic nature, there is an inherent randomness in the system performance measure \( X_{ij} \). Thus, it is difficult to be absolutely sure that a correct selection (CS) from amongst the alternatives can be made. However, we can select the alternative whose population mean is less than the next best population mean by a prescribed value \( d^* \), with a given probability \( P^* \). The exact formulation then becomes,

\[
P\{\text{CS}\} \geq P^*, \text{ such that } \mu_{i2} - \mu_{i1} \geq d^*
\]

where \( P^* \) and \( d^* \) are specified by the analyst. The procedure involves a "two-stage" sampling. In the first stage we make a fixed number of replications of each policy, and then we use the resulting variances to determine the number of additional replications needed for each policy, to reach a decision. Since we are considering independent replications, it can be assumed
that the $X_{ij}$'s are independent.

Let $n_0$ - number of replications for each of the $k$ policies in the first stage. The recommended value of $n_0$ is at least 15 (Law & Kelton, 1982).

The first stage sample means and variances are given by Eqn (1) and Eqn (2) as

$$\overline{X}_{i(n_0)} = \frac{\sum_{j=1}^{n_0} X_{ij}}{n_0} \quad \text{....................(1)}$$

$$s_i^2(n_0) = \frac{\sum_{j=1}^{n_0} (X_{ij} - \overline{X}_{i(n_0)})^2}{n_0 - 1} \quad \text{........(2)}$$

for $i = 1, 2, ... , k$.

Now, if $N_i$ is the total sample size needed for policy 'i', we have:

$$N_i = \max\left( n_0 + 1, \frac{h_1 \sum_{j=1}^{n_0} (X_{ij} - \overline{X}_{i(n_0)})^2}{(d^*)^2} \right) \quad \text{........(3)}$$

where $\lceil z \rceil$ is the smallest integer that is greater than or equal to the real number $z$, and $h_1$ (which depends on $k$, $P^*$ and $n_0$) is a constant. The values of $h_1$ for different values of $k$, $P^*$, and $n_0$ are provided in the tables listed by Law & Kelton (1982).

To obtain the second stage sample means we need $(N_i - n_0)$ more replications of system 'i' (i = 1, 2, ...
The second stage sample means is calculated using the formula in Eqn(4).

\[
\bar{X}_i (N_i) = \frac{\sum_{j=n_0+1}^{N_i} X_{ij}}{N_i - n_0} \quad \text{..................(4)}
\]

The number of runs, \(n_0\) and \((N_i - n_0)\), for the two stages are different. As a result of this the first stage and the second stage sample means have to be weighted to obtain the overall mean. The weights \(W_{i1}\) and \(W_{i2}\), assigned to the first stage and the second stage, are defined as:

\[
W_{i1} = \frac{n_0}{N_i} \left( 1 + \left\{ 1 - \frac{N_i}{n_0} \left[ 1 - \frac{(N_i - n_0)(d^*)^2}{h_1 s_i(n_0)^2} \right] \right\}^{1/2} \right) \quad \text{..................(5)}
\]

and

\[
W_{i2} = 1 - W_{i1}, \quad (i=1,2,...,k) \quad \text{..................(6)}
\]

The weighted sample means for policy 'i' is given by Eqn(7) as

\[
\bar{X}_i (N_i) = W_{i1} X_i (n_0) + W_{i2} X_i (N_i - n_0) \quad \text{..................(7)}
\]

These calculations that are given in Eqn(1) through Eqn(7) are performed for all the 'k' policies. The weighted sample means \(\bar{X}_i (N_i)\) are then used to select the policy. Depending on the system performance measure under consideration, the policy that results in the smallest or largest value of \(\bar{X}_i (N_i)\) is selected. One important
point to be noted here is the selection of $P^*$ and $d^*$ which ultimately depends on the analyst's goal and the particular system under investigation. $P^*$ and $d^*$ could be chosen after the first stage sampling.

This selection procedure is explained in Section 5.2.1, Section 5.2.2 and Section 5.2.3 with the help of examples. Since five scheduling rules (policies) are under consideration, we have $k=5$. Policy 'i' ($i=1,2,3,4,5$) is coded as follows:

- $i=1$ -- Random selection rule (RANDOM)
- $i=2$ -- Fewest operations remaining (FOPR)
- $i=3$ -- Most operations remaining (MOPR)
- $i=4$ -- Shortest processing time (SPT)
- $i=5$ -- Longest processing time (LPT)

5.2 Problem data

The problem data considered in this section, to illustrate the application of the simulation model, represent the typical parts spectrum and machine variety found in flexible manufacturing systems. The parts considered are of the non-rotational (prismatic) type and the machines used in the system are general purpose horizontal and vertical machining centers.
5.2.1 Problem 1

The FMS assumed for this problem consists of five machining centers, viz., three vertical machining centers (Machine # 1, 2 and 5) and two horizontal machining centers (Machine # 3 and 4). All these machines are laid out in a single lane as shown in Fig.12. The sketches and process sheets of the set of parts to be processed by this system are given in Appendix-F. The list of all the fixture types and the cutting tools that are required for the different operations of these parts are provided in Appendix-G. Six part types form the parts spectrum for this problem. The summary of the part type data for these six parts are shown in Table 1. Table 2 gives the summary of the system layout data and Table 3 lists the quantities of the various resources available. The travel times and the speed details of the different material handling systems are shown in Table 4.

5.2.1.1 Selection of the scheduling rule

These input data were organised into different data files using Program 1. The simulation of the FMS was carried out for each of the five scheduling rules. Following the observations made by Law & Kelton (1982) on the value of the first stage sample size, a value of 20
Fig. 12 Layout of the FMS - Problem 1
Table 1

Summary of part type data - Problem 1

<table>
<thead>
<tr>
<th>Part Type</th>
<th>Batch Size</th>
<th>Prty</th>
<th>Opn No.</th>
<th>Proc. Time (mins)</th>
<th>FT</th>
<th>Machine(s)</th>
<th>Tools required</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
<td>NO</td>
<td>1</td>
<td>24.00</td>
<td>1</td>
<td>1 or 2 or 5</td>
<td>13,14,8,24</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>24.00</td>
<td>1</td>
<td>1 or 2 or 5</td>
<td>13,14,8,24</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>18.00</td>
<td>1</td>
<td>3 or 4</td>
<td>15,16,8,24</td>
</tr>
<tr>
<td>2</td>
<td>9</td>
<td>NO</td>
<td>1</td>
<td>31.00</td>
<td>2</td>
<td>1 or 2 or 5</td>
<td>17,18,9,25,7</td>
</tr>
<tr>
<td>3</td>
<td>7</td>
<td>NO</td>
<td>1</td>
<td>6.00</td>
<td>3</td>
<td>1 or 2 or 5</td>
<td>19,20</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>23.00</td>
<td>3</td>
<td>3 or 4</td>
<td>19,20,17,18,21,22</td>
</tr>
<tr>
<td>4</td>
<td>12</td>
<td>NO</td>
<td>1</td>
<td>9.00</td>
<td>4</td>
<td>1 or 2 or 5</td>
<td>8,10,26</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>17.00</td>
<td>4</td>
<td>3 or 4</td>
<td>15,16,5,6,3,4,11,27,29</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
<td>NO</td>
<td>1</td>
<td>36.00</td>
<td>3</td>
<td>1 or 2 or 5</td>
<td>17,18,12,28,30</td>
</tr>
<tr>
<td>6</td>
<td>7</td>
<td>NO</td>
<td>1</td>
<td>8.00</td>
<td>5</td>
<td>1 or 2 or 5</td>
<td>19,20</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>14.00</td>
<td>5</td>
<td>1 or 2 or 5</td>
<td>19,20,8,10,26</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>21.00</td>
<td>6</td>
<td>4</td>
<td>21,23,1,2,5,6</td>
</tr>
</tbody>
</table>

Note: Prty - Priority, Opn. No. - Operation Number, Proc. Time - Processing Time, FT - Fixture type
Table 2

Summary of system layout data - Problem 1

<table>
<thead>
<tr>
<th>MACHINE</th>
<th>LANE</th>
<th>DISTANCE FROM MACHINE TO</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>LOADING STATION</td>
<td>UNLOADING STATION</td>
<td>TOOL CRIB</td>
<td></td>
</tr>
<tr>
<td>1 - VMC</td>
<td>1</td>
<td>10.00</td>
<td>10.00</td>
<td>50.00</td>
<td></td>
</tr>
<tr>
<td>2 - VMC</td>
<td>1</td>
<td>20.00</td>
<td>20.00</td>
<td>40.00</td>
<td></td>
</tr>
<tr>
<td>3 - HMC</td>
<td>1</td>
<td>30.00</td>
<td>30.00</td>
<td>30.00</td>
<td></td>
</tr>
<tr>
<td>4 - HMC</td>
<td>1</td>
<td>40.00</td>
<td>40.00</td>
<td>20.00</td>
<td></td>
</tr>
<tr>
<td>5 - VMC</td>
<td>1</td>
<td>50.00</td>
<td>50.00</td>
<td>10.00</td>
<td></td>
</tr>
</tbody>
</table>

Note: All the distances are in meters

VMC - Vertical Machining Center
HMC - Horizontal Machining Center
### Table 3

**Summary of resource data — Problem 1**

<table>
<thead>
<tr>
<th>Resource name</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loading crane</td>
<td>1</td>
</tr>
<tr>
<td>Unloading crane</td>
<td>1</td>
</tr>
<tr>
<td>Loaders</td>
<td>1</td>
</tr>
<tr>
<td>Unloaders</td>
<td>1</td>
</tr>
<tr>
<td>Loading AGVs</td>
<td>1</td>
</tr>
<tr>
<td>Unloading AGVs</td>
<td>1</td>
</tr>
<tr>
<td>Pallets</td>
<td>5</td>
</tr>
<tr>
<td>Fixture type 1</td>
<td>2</td>
</tr>
<tr>
<td>Fixture type 2</td>
<td>1</td>
</tr>
<tr>
<td>Fixture type 3</td>
<td>2</td>
</tr>
<tr>
<td>Fixture type 4</td>
<td>1</td>
</tr>
<tr>
<td>Fixture type 5</td>
<td>1</td>
</tr>
<tr>
<td>Fixture type 6</td>
<td>1</td>
</tr>
</tbody>
</table>

### Table 4

**Summary of speed and time details of the material handling systems — Problem 1**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed of the loading AGV</td>
<td>20.00 mts/min</td>
</tr>
<tr>
<td>Speed of the unloading AGV</td>
<td>20.00 mts/min</td>
</tr>
<tr>
<td>Speed of the tool conveyor</td>
<td>10.00 mts/min</td>
</tr>
<tr>
<td>Travel time for the loading crane</td>
<td>2.00 mins</td>
</tr>
<tr>
<td>Travel time for the unloading crane</td>
<td>2.00 mins</td>
</tr>
<tr>
<td>Loading time</td>
<td>Uniformly distributed between 2.00 mins and 3.00 mins</td>
</tr>
<tr>
<td>Unloading time</td>
<td>Uniformly distributed between 1.00 and 2.00 mins</td>
</tr>
</tbody>
</table>
was chosen for \( n_0 \). Twenty independent runs for each scheduling rule were made using different random number streams for each run. To ensure that each of these policies was tested under identical conditions, the random number streams for each policy were made identical. The makespan was chosen as the measure of performance of the system.

The first stage sampling for the five policies was done and the results are shown in Table 5. The following values of \( P^* \) and \( d^* \) were chosen for the analysis. \( P^* = .90 \), and \( d^* = 15 \) minutes

These values for \( P^* \) and \( d^* \) indicate that we want to be 90% confident that the difference in the makespan values for the selected policy and the next policy would be greater than or equal to 15 minutes. From the tables, for a value of \( k=5 \) and the above mentioned values of \( P^* \) and \( n_0 \), \( h_1 \) was found to be 2.747. The number of additional runs required \((N_i - n_0)\) for the \( i \)th policy \((i=1,2,\ldots,5)\) was calculated based on the results of the first-stage sampling and was found to be one. The additional run was conducted for each policy and the second-stage sampling procedure was applied. The weights \( W_{i1} \) and \( W_{i2} \) for each policy were calculated. From these weights, the weighted sample means for the system performance measure under consideration were determined. Table 5 shows the weighted sample means of
Table 5

Weighted sample means of makespan - Problem 1

<table>
<thead>
<tr>
<th>i</th>
<th>X_{i1}(20)</th>
<th>s_{i1}(20)</th>
<th>N_{i1}</th>
<th>X_{i1}(N_{i1} - 20)</th>
<th>W_{i1}</th>
<th>W_{i2}</th>
<th>X_{i1}(N_{i1}) (mins)</th>
<th>90% confidence interval (mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1145.676</td>
<td>620.110</td>
<td>21</td>
<td>1159.036</td>
<td>.9734</td>
<td>.0266</td>
<td>1146.031</td>
<td>1145.676 ± 43.08</td>
</tr>
<tr>
<td>2</td>
<td>1128.065</td>
<td>152.677</td>
<td>21</td>
<td>1127.931</td>
<td>1.3274</td>
<td>-.3274</td>
<td>1128.109</td>
<td>1128.065 ± 21.38</td>
</tr>
<tr>
<td>3</td>
<td>1177.570</td>
<td>288.320</td>
<td>21</td>
<td>1201.931</td>
<td>1.1829</td>
<td>-.1829</td>
<td>1173.152</td>
<td>1177.570 ± 29.38</td>
</tr>
<tr>
<td>4</td>
<td>1158.917</td>
<td>443.128</td>
<td>21</td>
<td>1155.390</td>
<td>1.0892</td>
<td>-.0892</td>
<td>1159.232</td>
<td>1158.917 ± 36.42</td>
</tr>
<tr>
<td>5</td>
<td>1173.930</td>
<td>462.621</td>
<td>21</td>
<td>1173.800</td>
<td>1.0790</td>
<td>-.0790</td>
<td>1173.940</td>
<td>1173.930 ± 37.20</td>
</tr>
</tbody>
</table>

---

First stage sampling  Second stage sampling

[ "i" refers to policy ]

i = 1 - Random selection rule
i = 2 - Fewest operations remaining
i = 3 - Most operations remaining
i = 4 - Shortest processing time
i = 5 - Longest processing time

p^* = .90, \( d^* = 15 \text{ mins} \), k=5 and \( h_1 = 2.747 \)
the makespan for each rule. From the column in Table 5 corresponding to the weighted sample means of the makespan \( \bar{X}_i(N_i) \) for each scheduling policy, it can be seen that the Fewest Operations Remaining (FOPR) rule results in the shortest expected makespan. Hence, the FOPR rule is selected. The last column in Table 5 gives the 90% confidence interval of the makespan for the five policies. The formula to obtain the 90% confidence interval is given in Eqn (8) as

\[
\bar{X} \pm \left( \frac{s}{\sqrt{n}} \right) \cdot (t_{n-1, 1-\alpha/2}) \quad \ldots \ldots \quad (8)
\]

where, 
- \( n \) — number of simulation runs
- \( \bar{X} \) — mean of the \( n \) runs
- \( s \) — standard deviation of \( X \) in the \( n \) runs
- \( \alpha \) — level of significance.

The 90% confidence interval for policy 2, the FOPR rule, is \( 1128.065 \pm 21.38 \) minutes, i.e., we can be 90% confident the makespan will be between 1106.685 minutes and 1149.445 minutes, when we are using this policy.

### 5.2.1.2 Experimental design setup

As proposed earlier, after the selecting the scheduling policy, the next stage is to study the effects of the important resources on the makespan, using this policy. This is done by setting up a suitable experimental design. A \( 2^k \) factorial design was chosen.
for this purpose. The 'k' factors, or important resources, are set at two levels - a high level and a low level. At the outset, though it might seem that each resource can have more than two levels, in reality, the hardware constraints, the operational constraints, the technical constraints, etc. do not permit certain resources to have more than two levels. For example, due to operational constraints, it is not feasible to have more than one loading or unloading crane to move the parts between the central parts storage and the loading and unloading stations.

The selection of the important resources is based on their respective utilizations. Table 6 gives the list of the various resources that were used by the system, their quantities, and their respective average utilizations for twenty one runs using the FOPR rule. Resources used in a FMS are classified as shared resources, those that are used by all the part types and specific resources, those that are used by only a certain part type. The fixture types belong to the latter category while the other resources used by this system belong to the former category.

Consider the shared resources that are at their minimum level, i.e., having a quantity of one. We can see that the loading AGV was utilized on the average to a larger extent than the rest, say, loading crane or
Table 6

Resource quantities and utilization - FOPR rule

<table>
<thead>
<tr>
<th>Resource</th>
<th>Quantity</th>
<th>Average Utilization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loading crane</td>
<td>1</td>
<td>53.3%</td>
</tr>
<tr>
<td>Unloading crane</td>
<td>1</td>
<td>66.3%</td>
</tr>
<tr>
<td>Loader</td>
<td>1</td>
<td>53.3%</td>
</tr>
<tr>
<td>Unloader</td>
<td>1</td>
<td>49.8%</td>
</tr>
<tr>
<td>Loading AGV</td>
<td>1</td>
<td>74.3%</td>
</tr>
<tr>
<td>Unloading AGV</td>
<td>1</td>
<td>49.8%</td>
</tr>
<tr>
<td>Pallet</td>
<td>5</td>
<td>69.8%</td>
</tr>
<tr>
<td>Fixture type 1</td>
<td>2</td>
<td>30.6%</td>
</tr>
<tr>
<td>Fixture type 2</td>
<td>1</td>
<td>42.4%</td>
</tr>
<tr>
<td>Fixture type 3</td>
<td>2</td>
<td>50.8%</td>
</tr>
<tr>
<td>Fixture type 4</td>
<td>1</td>
<td>72.5%</td>
</tr>
<tr>
<td>Fixture type 5</td>
<td>1</td>
<td>44.2%</td>
</tr>
<tr>
<td>Fixture type 6</td>
<td>1</td>
<td>27.0%</td>
</tr>
</tbody>
</table>

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loader. It can also be seen that there are five pallets that were on the average utilized at approximately 70%, i.e., only 3.5 pallets out of the five pallets were utilized on the average. Considering the specific resources, namely, the different fixture types, we can see that there are two units of fixture type 1 which were utilized about 30% on the average. This again is a low value considering the fact that there are two fixtures of the same type. These three resources - loading AGV, pallet and fixture type 1 - were considered as important resources for this problem. To study the effects of these resources a $2^3$ factorial design was set up with each factor at two levels. Table 7 gives the different treatment combinations of these three factors. The design matrix that facilitates calculations of the factor effects and interactions is shown in Table 8. Ten simulation runs were made for the eight treatment combinations of these three factors (resources). The makespan (response) is also given in Table 8 for each treatment.

With the help of this design matrix, the main effects and the interactions were calculated and listed as shown in Table 9. The main effect of a factor $j$ is the average change in response due to moving $j$ from its '- level to its '+' level while holding all the other factors fixed and is calculated using the notations in the design matrix. For example, if $R_1, R_2, \ldots , R_8$ are the
Table 7

Treatment combinations for the three resources

<table>
<thead>
<tr>
<th>TREATMENT #</th>
<th>RESOURCE LEVELS</th>
<th>LOADING AGV</th>
<th>PALLET</th>
<th>FIXTURE TYPE 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>1 (-)</td>
<td>3 (-)</td>
<td>1 (-)</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>2 (+)</td>
<td>3 (-)</td>
<td>1 (-)</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>1 (-)</td>
<td>5 (+)</td>
<td>1 (-)</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>2 (+)</td>
<td>5 (+)</td>
<td>1 (-)</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>1 (-)</td>
<td>3 (-)</td>
<td>2 (+)</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>2 (+)</td>
<td>3 (-)</td>
<td>2 (+)</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>1 (-)</td>
<td>5 (+)</td>
<td>2 (+)</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>2 (+)</td>
<td>5 (+)</td>
<td>2 (+)</td>
</tr>
</tbody>
</table>

Note: The signs within parentheses indicate a high or low level of each resource.

(+): High level
(-): Low level
Table 8

$2^3$ factorial design matrix - FOPR rule

<table>
<thead>
<tr>
<th>TREATMENT</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>AB</th>
<th>AC</th>
<th>BC</th>
<th>ABC</th>
<th>Makespan (mins) 90% confidence interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>1401.599 ± 9.36</td>
</tr>
<tr>
<td>a</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>1382.950 ± 15.87</td>
</tr>
<tr>
<td>b</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>1115.009 ± 33.50</td>
</tr>
<tr>
<td>ab</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1087.655 ± 28.78</td>
</tr>
<tr>
<td>c</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>1421.984 ± 8.98</td>
</tr>
<tr>
<td>ac</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>1390.228 ± 16.92</td>
</tr>
<tr>
<td>bc</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>1127.930 ± 26.09</td>
</tr>
<tr>
<td>abc</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>1089.061 ± 16.66</td>
</tr>
</tbody>
</table>

Factor A - Loading AGV
Factor B - Pallet
Factor C - Fixture type 1

Levels of Factor A - 1 and 2
Levels of Factor B - 3 and 5
Levels of Factor C - 1 and 2

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### Table 9

**Effects of factors on system response - FOPR rule**

<table>
<thead>
<tr>
<th>Effect</th>
<th>Makespan</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main effects</strong></td>
<td></td>
</tr>
<tr>
<td>Loading AGV A</td>
<td>-29.1500</td>
</tr>
<tr>
<td>Pallet B</td>
<td>-294.2765</td>
</tr>
<tr>
<td>Fixture type 1 C</td>
<td>10.4975</td>
</tr>
<tr>
<td><strong>Two factor interactions</strong></td>
<td></td>
</tr>
<tr>
<td>A X B</td>
<td>-3.9545</td>
</tr>
<tr>
<td>A X C</td>
<td>-6.1555</td>
</tr>
<tr>
<td>B X C</td>
<td>-3.3340</td>
</tr>
<tr>
<td><strong>Three factor interactions</strong></td>
<td></td>
</tr>
<tr>
<td>A X B X C</td>
<td>.3993</td>
</tr>
</tbody>
</table>

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responses for each of the eight treatments, respectively, the main effect of factor A \( (e_A) \) is given by the formula, (Law & Kelton, 1982)

\[
ed_A = \frac{(R_2 - R_1) + (R_4 - R_3) + (R_6 - R_5) + (R_8 - R_7)}{4} \quad \text{.....(9)}
\]

Similarly, the interaction effect for the factors A and B is given by Eqn (10),

\[
ed_{AB} = \frac{R_1 - R_2 - R_3 + R_4 + R_5 - R_6 - R_7 + R_8}{4} \quad \text{....(10)}
\]

5.2.1.3 Discussion

(i) From Table 9 it is clear that the two factor interactions are small compared to the main effects of factors A and B. The three factor interaction is also negligible. However, the main effect due to factor B, i.e., the pallet, is quite significant in decreasing the response (makespan). It can be seen that an increase in the number of pallets from a low level of three to a high level of five resulted in a considerable decrease in the makespan. The number of parts circulating inside the system is the same as the number of pallets used by the system because every fixtured part type is mounted on a pallet irrespective of the fixture type or part type. Hence, increasing the number of pallets in the system increases the number of parts circulating in the system.
thereby decreasing the makespan. The FMS consists of five machines and with only three pallets being used, at least two machines are idle at any point in time during the operation of the system. Due to the non-availability of the pallets, parts that are selected to enter the system for processing are forced to wait, thereby increasing the total time the parts spend in the system.

(ii) The main effect of factor A, i.e., the loading AGV, is not as much as that of factor B, the pallet (Table 9). Increasing the number of loading AGV's resulted in a decrease in the makespan. However, the decrease in the makespan due to the increase in the number of pallets is ten times larger than that due to the increase in the number of loading AGV's. This can be attributed to the traffic congestions on the loading track. Though an increase in the number of loading AGVs increases the number of parts circulating inside the system, a loading AGV spends some time waiting at the loading station whenever there is another AGV travelling on the same track. As a result of this, increasing the number of loading AGV's did not result in a significant reduction in the makespan.

(iii) Increasing factor C, i.e., the fixture type 1, resulted in increasing the makespan (Table 9). The fixture, being a more specific resource, is used only by part type 1 and probably during the entire operation of
the system, there was no part type 1 that was waiting for fixture type 1. However, it should be mentioned here that the effect of fixture type 1 depends also on the batch size of part type 1. If the batch size of this part type is very high compared to the batch sizes of the rest of the parts spectrum, the number of parts waiting for this fixture type would be high. In such conditions, increasing the quantity of this fixture would tend to decrease the makespan. In this example, since the batch size of part type 1 was small compared to the other part types, increasing the number of units of fixture type 1 did not result in a decrease in the makespan.

(iv) Table 10 lists the average machine utilizations for the different treatment combinations. Considering all the treatments, it can be seen that Machine 1 was utilized to a larger extent compared to the other machines. This is due to the proximity of this machine to the loading and unloading stations that always results in Machine 1 being selected whenever it is available. Higher levels of the pallets (Treatment 3, 4, 7, 8 — Table 10) resulted in higher utilizations for all the machines. This is because of the significant decrease in the makespan whenever there is an increase in the number of pallets, as seen earlier. Data of this type on machine utilizations are useful in deciding whether a particular machine should be kept running or shut down.
Table 10

Average machine utilizations - Problem 1

<table>
<thead>
<tr>
<th>TRTMNT.</th>
<th>MACHINE</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>33.4</td>
<td>27.7</td>
<td>25.0</td>
<td>18.0</td>
<td>23.3</td>
</tr>
<tr>
<td>2</td>
<td>33.0</td>
<td>28.3</td>
<td>26.5</td>
<td>17.0</td>
<td>24.2</td>
</tr>
<tr>
<td>3</td>
<td>49.2</td>
<td>37.9</td>
<td>33.3</td>
<td>20.7</td>
<td>19.3</td>
</tr>
<tr>
<td>4</td>
<td>51.3</td>
<td>37.9</td>
<td>35.5</td>
<td>19.9</td>
<td>19.6</td>
</tr>
<tr>
<td>5</td>
<td>31.3</td>
<td>28.2</td>
<td>24.7</td>
<td>17.6</td>
<td>23.7</td>
</tr>
<tr>
<td>6</td>
<td>32.0</td>
<td>29.4</td>
<td>25.7</td>
<td>17.6</td>
<td>23.7</td>
</tr>
<tr>
<td>7</td>
<td>43.0</td>
<td>35.0</td>
<td>32.6</td>
<td>20.8</td>
<td>26.8</td>
</tr>
<tr>
<td>8</td>
<td>46.9</td>
<td>38.1</td>
<td>32.8</td>
<td>22.5</td>
<td>23.7</td>
</tr>
</tbody>
</table>
From Table 10, we can see that Machine 4 has been utilized to the lowest extent compared to the other machines. Under such conditions a decision could be made whether this machine should be used to process this particular batch of part types. The simulation model could be used to evaluate the performance of the system without Machine 4.

(v) The average utilizations of the resources for the different treatment combinations are shown in Table 11. The loading crane, loader and loading AGV are resources that are seized simultaneously. After the unit has been mounted on the loading AGV, the loading crane and the loader are released while the loading AGV is not released until it has transported the unit to the respective machine. As a result of this, it can be found from Table 11 that the loading AGV is utilized to a higher extent than the loading crane and the loader.

The unloading crane, unloader and unloading AGV are seized simultaneously. However, after dismantling the unit at the unloading station, the unloader and the unloading AGV are released while the unloading crane is not released until it has transported the part to the central parts storage. Hence, the unloading crane is utilized to a higher extent than the unloading AGV and the unloader.

Considering the pallets and the loading AGV, it
### Table 11

#### Average resource utilizations - Problem 1

<table>
<thead>
<tr>
<th>TRT.</th>
<th>Crane</th>
<th>Ucrane</th>
<th>Load</th>
<th>Uload</th>
<th>AGV-L</th>
<th>AGV-UL</th>
<th>Pallet</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>43.0</td>
<td>54.2</td>
<td>43.0</td>
<td>40.1</td>
<td>60.7</td>
<td>40.1</td>
<td>85.3</td>
</tr>
<tr>
<td>2</td>
<td>43.7</td>
<td>54.9</td>
<td>43.5</td>
<td>41.5</td>
<td>30.8</td>
<td>41.5</td>
<td>86.9</td>
</tr>
<tr>
<td>3</td>
<td>54.0</td>
<td>66.2</td>
<td>54.0</td>
<td>49.5</td>
<td>74.4</td>
<td>49.5</td>
<td>72.8</td>
</tr>
<tr>
<td>4</td>
<td>55.4</td>
<td>67.7</td>
<td>55.4</td>
<td>50.6</td>
<td>38.1</td>
<td>50.6</td>
<td>76.1</td>
</tr>
<tr>
<td>5</td>
<td>42.3</td>
<td>53.3</td>
<td>42.3</td>
<td>40.3</td>
<td>59.7</td>
<td>40.3</td>
<td>84.0</td>
</tr>
<tr>
<td>6</td>
<td>43.3</td>
<td>54.4</td>
<td>43.3</td>
<td>41.1</td>
<td>30.5</td>
<td>41.1</td>
<td>85.8</td>
</tr>
<tr>
<td>7</td>
<td>53.3</td>
<td>66.3</td>
<td>53.3</td>
<td>49.8</td>
<td>74.3</td>
<td>49.8</td>
<td>69.8</td>
</tr>
<tr>
<td>8</td>
<td>55.2</td>
<td>68.8</td>
<td>55.2</td>
<td>51.7</td>
<td>38.5</td>
<td>51.7</td>
<td>73.9</td>
</tr>
</tbody>
</table>

**Note:**
- Crane — Loading crane
- Ucrane — Unloading crane
- Load — Loader
- ULoad — Unloader
- AGV-L — Loading AGV
- AGV-UL — Unloading AGV
can be seen that increasing their levels significantly decreases the makespan (Table 8) and their respective utilizations. A similar observation has been reported by Chang et al. (1986).

(vi) The average utilizations of the specific resources, namely, the fixture types, are shown in Table 12. It can be seen that the high utilizations for all the fixture types, except fixture type 1, occurs for the four treatments (Treatments 3, 4, 7 and 8—Table 12). However, for the fixture type 1, it can be seen that high utilizations occur only for treatments 3 and 4. Increasing this fixture type from one to two units resulted in a decrease in utilization per unit (Treatments 5, 6, 7 and 8—Table 12).

The above discussion based on the results of the experimental design can be used as a basis to decide the quantities of the resources to be used to process a particular batch of part types. Due considerations should be given to the cost factors such as, the cost of a pallet, or a loading AGV, or fixture, etc., before a final decision can be made.

5.2.2 Problem 2

The parts spectrum and the machine variety considered for this problem are the same as that of
<table>
<thead>
<tr>
<th>TRT</th>
<th>FIXTURE TYPES</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>1</td>
<td>43.5</td>
<td>32.2</td>
<td>36.2</td>
<td>56.0</td>
<td>31.1</td>
</tr>
<tr>
<td>2</td>
<td>44.2</td>
<td>32.9</td>
<td>37.0</td>
<td>57.5</td>
<td>31.5</td>
</tr>
<tr>
<td>3</td>
<td>61.3</td>
<td>44.2</td>
<td>52.6</td>
<td>78.1</td>
<td>47.6</td>
</tr>
<tr>
<td>4</td>
<td>66.4</td>
<td>44.4</td>
<td>54.8</td>
<td>82.7</td>
<td>49.0</td>
</tr>
<tr>
<td>5</td>
<td>21.5</td>
<td>30.9</td>
<td>36.3</td>
<td>54.2</td>
<td>30.6</td>
</tr>
<tr>
<td>6</td>
<td>22.1</td>
<td>31.6</td>
<td>37.5</td>
<td>55.1</td>
<td>30.9</td>
</tr>
<tr>
<td>7</td>
<td>30.6</td>
<td>42.3</td>
<td>50.8</td>
<td>72.5</td>
<td>44.2</td>
</tr>
<tr>
<td>8</td>
<td>32.6</td>
<td>45.2</td>
<td>53.8</td>
<td>77.2</td>
<td>46.5</td>
</tr>
</tbody>
</table>

Table 12
Average fixture utilizations - Problem 1
Problem 1. However, one of the part types has a priority over the other part types. This type of situation is common in practice. Part types ordered by important customers, part types to be processed urgently, etc. are always given a priority over the other part types in the batch. The simulation model is designed such that it can be adapted to such situations.

The summary of the part data for Problem 2 is the same as that for Problem 1 (Table 1) except for part type 5 that has been assigned a priority. The system layout data, resource data, and the speed and time details of the different material handling systems for this problem are also the same as that for Problem 1 (Tables 2, 3 and 4).

Table 13 shows the results of the first stage and second stage sampling procedures applied to select the scheduling policy. Based on the weighted sample means of the makespan, the RANDOM rule is selected. The only difference in the input data for Problems 1 and 2 is the inclusion of a part type (part type 5) a higher priority. However, the selected scheduling policy for both these problems are different.

5.2.3 Problem 3

Problem 3 demonstrates the application of the simulation model to multiple-lane layouts. The layout of
### Table 13

**Weighted sample means of makespan - Problem 2**

<table>
<thead>
<tr>
<th></th>
<th>$-\left(1\right)$</th>
<th>$s_{1}(20)$</th>
<th>$N_{1}$</th>
<th>$-\left(2\right)$</th>
<th>$W_{11}$</th>
<th>$W_{12}$</th>
<th>$\bar{x}<em>{1}(N</em>{1})$</th>
<th>90% confidence interval (mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1115.393</td>
<td>654.923</td>
<td>21</td>
<td>1137.398</td>
<td>1.1305</td>
<td>-.1305</td>
<td>1112.527</td>
<td>1115.393 ± 44.27</td>
</tr>
<tr>
<td>2</td>
<td>1123.847</td>
<td>606.492</td>
<td>21</td>
<td>1117.983</td>
<td>1.1470</td>
<td>-.1470</td>
<td>1124.708</td>
<td>1123.847 ± 42.60</td>
</tr>
<tr>
<td>3</td>
<td>1142.270</td>
<td>317.766</td>
<td>21</td>
<td>1156.639</td>
<td>1.2893</td>
<td>-.2893</td>
<td>1138.113</td>
<td>1142.270 ± 30.84</td>
</tr>
<tr>
<td>5</td>
<td>1128.840</td>
<td>621.140</td>
<td>21</td>
<td>1120.845</td>
<td>1.1419</td>
<td>-.1419</td>
<td>1129.974</td>
<td>1128.840 ± 43.11</td>
</tr>
</tbody>
</table>

[ *'i' refers to policy *]

1 = 1 - Random selection rule  
2 = 2 - Fewest operations remaining  
3 = 3 - Most operations remaining  
4 = 4 - Shortest processing time  
5 = 5 - Longest processing time

\[ p^* = .90, \ d^* = 20 \text{ mins}, \ k=5 \text{ and } h_1 = 2.747 \]
the FMS for this problem consists of two lanes, with three machines on lane 1 and two machines on lane 2 (Fig. 13). The first four part types form the parts spectrum for this problem. The summary of the part type data for these four parts are shown in Table 14. Table 15 gives the summary of the system layout data and Table 16 lists the quantities of the various resources available. The travel times and the speed details of the different material handling systems are shown in Table 17.

Table 18 shows the results of the first stage and second stage sampling procedures applied to select the scheduling policy. Based on the weighted sample means of the makespan, the Longest Processing Time (LPT) rule is selected. From the analysis of these three problems it can be seen that variations in the input data result in the selection of different scheduling. This is similar to the observation made by Stecke and Solberg (1981).

The use of the simulation model to address the operating problems of a FMS, namely, the scheduling policy to be followed, has been explained through the use of examples in Section 5.2.1, Section 5.2.2 and Section 5.2.3. A detailed analysis was conducted for Problem 1. The $2^k$ factorial design that was proposed to study the effects of the important resources on the system performance was applied to Problem 1. The value of $k$ was equal to 3. However, for higher values of $k$ the number of
Fig. 13  Layout of the FMS - Problem 3

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## Table 14

Summary of part type data - Problem 3

<table>
<thead>
<tr>
<th>Part Type</th>
<th>Batch Size</th>
<th>Prty No.</th>
<th>Opn No.</th>
<th>Proc. Time (mins)</th>
<th>FT</th>
<th>Machine(s)</th>
<th>Tools required</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>NO</td>
<td>1</td>
<td>24.00</td>
<td>1</td>
<td>1 or 2 or 5</td>
<td>13,14,8,24</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>24.00</td>
<td>1</td>
<td>1 or 2 or 5</td>
<td>13,14,8,24</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>18.00</td>
<td>1</td>
<td>3 or 4</td>
<td>15,16,8,24</td>
</tr>
<tr>
<td>2</td>
<td>9</td>
<td>NO</td>
<td>1</td>
<td>31.00</td>
<td>2</td>
<td>1 or 2 or 5</td>
<td>17,18,9,25,7</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>NO</td>
<td>1</td>
<td>6.00</td>
<td>3</td>
<td>1 or 2 or 5</td>
<td>19,20</td>
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<td></td>
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<td></td>
<td>2</td>
<td>23.00</td>
<td>3</td>
<td>3 or 4</td>
<td>19,20,17,18,21,22</td>
</tr>
<tr>
<td>4</td>
<td>41</td>
<td>NO</td>
<td>1</td>
<td>9.00</td>
<td>4</td>
<td>1 or 2 or 5</td>
<td>8,10,26</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>17.00</td>
<td>4</td>
<td>3 or 4</td>
<td>15,16,5,6,3,4,11,27,29</td>
</tr>
</tbody>
</table>

Note: Prty - Priority, Opn. No. - Operation Number, Proc. Time - Processing Time, FT - Fixture type
Table 15

Summary of system layout data - Problem 3

<table>
<thead>
<tr>
<th>MACHINE</th>
<th>LANE</th>
<th>DISTANCE FROM MACHINE TO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>LOADING STATION</td>
</tr>
<tr>
<td>1 - VMC</td>
<td>1</td>
<td>10.00</td>
</tr>
<tr>
<td>2 - VMC</td>
<td>1</td>
<td>20.00</td>
</tr>
<tr>
<td>3 - HMC</td>
<td>1</td>
<td>30.00</td>
</tr>
<tr>
<td>4 - HMC</td>
<td>2</td>
<td>15.00</td>
</tr>
<tr>
<td>5 - VMC</td>
<td>2</td>
<td>25.00</td>
</tr>
</tbody>
</table>

Note: All the distances are in meters

VMC - Vertical Machining Center
HMC - Horizontal Machining Center
Table 16

Summary of resource data - Problem 3

<table>
<thead>
<tr>
<th>Resource name</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loading crane</td>
<td>1</td>
</tr>
<tr>
<td>Unloading crane</td>
<td>1</td>
</tr>
<tr>
<td>Loaders</td>
<td>1</td>
</tr>
<tr>
<td>Unloaders</td>
<td>1</td>
</tr>
<tr>
<td>Loading AGVs</td>
<td>1</td>
</tr>
<tr>
<td>Unloading AGVs</td>
<td>1</td>
</tr>
<tr>
<td>Pallets</td>
<td>5</td>
</tr>
<tr>
<td>Fixture type 1</td>
<td>1</td>
</tr>
<tr>
<td>Fixture type 2</td>
<td>1</td>
</tr>
<tr>
<td>Fixture type 3</td>
<td>1</td>
</tr>
<tr>
<td>Fixture type 4</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 17

Summary of speed and time details of the material handling systems - Problem 3

- Speed of the loading AGV = 20.00 mts/min
- Speed of the unloading AGV = 20.00 mts/min
- Speed of the tool conveyor = 10.00 mts/min
- Travel time for the loading crane = 2.00 mins
- Travel time for the unloading crane = 2.00 mins
- Loading time - Uniformly distributed between 2.00 mins and 3.00 mins
- Unloading time - Uniformly distributed between 1.00 and 2.00 mins
Table 18

Weighted sample means of makespan - Problem 3

<table>
<thead>
<tr>
<th>i</th>
<th>(-\frac{(1)}{X_i(20)})</th>
<th>(\frac{2}{s_1(20)})</th>
<th>(N_i)</th>
<th>(-\frac{(2)}{X_i(N_i - 20)})</th>
<th>(W_{11})</th>
<th>(W_{12})</th>
<th>(X_i(N_i)) (mins)</th>
<th>90% confidence interval (mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2577.272</td>
<td>958.842</td>
<td>21</td>
<td>2565.385</td>
<td>1.0738</td>
<td>-0.0738</td>
<td>2577.721</td>
<td>2577.272 ± 53.57</td>
</tr>
<tr>
<td>2</td>
<td>2551.960</td>
<td>194.847</td>
<td>21</td>
<td>2551.807</td>
<td>1.4147</td>
<td>-0.4147</td>
<td>2552.023</td>
<td>2551.965 ± 24.15</td>
</tr>
<tr>
<td>3</td>
<td>2634.196</td>
<td>252.121</td>
<td>21</td>
<td>2636.078</td>
<td>1.3459</td>
<td>-0.3459</td>
<td>2633.545</td>
<td>2634.196 ± 27.47</td>
</tr>
<tr>
<td>4</td>
<td>2639.441</td>
<td>155.563</td>
<td>21</td>
<td>2622.835</td>
<td>1.4087</td>
<td>-0.4087</td>
<td>2647.423</td>
<td>2639.441 ± 21.57</td>
</tr>
<tr>
<td>5</td>
<td>2543.338</td>
<td>203.484</td>
<td>21</td>
<td>2538.988</td>
<td>1.4027</td>
<td>-0.4027</td>
<td>2545.091</td>
<td>2543.338 ± 24.68</td>
</tr>
</tbody>
</table>

First stage sampling — Second stage sampling

[ 'i' refers to policy ]

i = 1 - Random selection rule
i = 2 - Fewest operations remaining
i = 3 - Most operations remaining
i = 4 - Shortest processing time
i = 5 - Longest processing time

\(p^* = .90, \ d^* = 20\) mins, \(k=5\) and \(h_1 = 2.747\)
treatment combinations is large. In such situations a
$2^k$ factorial design with replicates would involve a
large amount of computer time. To avoid this, a
fractional factorial design could be employed in which
only 'p' factors out of the k important factors are
analysed (Law & Kelton, 1982). The choice of p is
subjective and depends on the analyst.

Except for the loading and unloading times which
are stochastic, the remaining times, like the processing
time, travel times, etc., are deterministic. However, if
these times are made stochastic the amount of randomness
that would be introduced into the output would be high.
Hence, a larger number of runs would be necessary to
reduce the variance of the output measures. Variance
reduction techniques could be applied to control the
variance under such conditions.
Chapter VI

SUMMARY

A microcomputer-based simulation model of an idealised FMS has been developed. Some features such as alternate routings, treatment of fixtures as resources and part types with priorities were included to make the model realistic. The model was developed on a microcomputer using SLAM and was made user-interactive. Five different scheduling rules were selected to be investigated by the model for each set of part types to be processed by the system. The simulation model has been designed such that it is adaptable to variations in the layout as shown in Fig. 2.

The statistical approach to select the scheduling policy and the experimental design setup used to aid the study of the effects of the important resources on system performance were explained through the use of examples. The simulation model is general enough to be applied to small- or medium-sized problems. The primary function of
the model is to act as a decision tool in selecting the scheduling policy for the part types that are processed by the system under consideration.

Though the model attempted to include some realistic aspects mentioned earlier, breakdown of machines or resources which is a common feature in most manufacturing systems has not been considered. Also, complicated FMS layouts could not be incorporated into a general program. Complicated scheduling rules were not considered by this model. It is in these directions that this model could be used for further work and enhanced to include additional features.
REFERENCES


10 REM ################################################################################
20 REM $  
30 REM $ PROGRAM TO INPUT THE PART DETAILS OF ALL THE PARTS THAT ARE USED $  
40 REM $ IN THE SIMULATION MODEL. THESE DETAILS WILL BE STORED IN $  
50 REM $ SEPARATE DATA FILES AND WILL BE ACCESSED BY THE $  
60 REM $ SLAM MAIN PROGRAM $  
70 REM $  
80 REM ################################################################################
90 REM
100 REM *** PROGRAM WRITTEN BY ----> THIRUVENADAM RAVI ***
110 REM
120 OPTION BASE 1
130 DIM IGD(3),IFT(10),PRT(10),IALM(90),ITool(100),JPRPT(25),NF(30),PARR(25,220),DULOM(9),DLOM(9),

140 REM CALLING THE VARIOUS SUBROUTINES
150 REM
160 REM
170 EOF
180 GOTO 350
190 CLS:COLOR 7,0,0:END
200 REM ################################################################################
210 REM $ SUBROUTINE TO DISPLAY FEATURES OF THE SEGMENT $  
220 REM ################################################################################
230 CLS:KEY OFF:COLOR 11,0,9:LOCATE 10,16:PRINT "[";STRING$(48,205);"
240 LOCATE 11,16:PRINT ";";STRING$(48,32);"
250 LOCATE 12,16:PRINT ";";LOCATE 12,22:PRINT "PROGRAM TO INPUT THE DATA THAT DRIVES ";LOCATE 1 
2,65:PRINT "]
260 LOCATE 13,16:PRINT ";";STRING$(48,32);"
270 LOCATE 14,16:PRINT ";";LOCATE 14,20:PRINT "THE SIMULATION MODEL DEVELOPED IN SLAM II";LOCATE 
E 14,65:PRINT "]
280 LOCATE 15,16:PRINT ";";STRING$(48,32);"
290 LOCATE 16,16:PRINT ";";STRING$(48,205);"
300 COLOR 30,0:LOCATE 25,14:PRINT "P R E S S S P A C E B A R TO C O N T I N U E "
310 IF INKEY$ < > "" THEN GOTO 310
320 PRO$=INKEY$
330 IF PRO$ < > "" THEN GOTO 320
340 RETURN
350 REM ################################################################################
360 REM $ SUBROUTINE TO DISPLAY THE MAIN MENU $  
370 REM ################################################################################
380 CLS:KEY OFF:COLOR 10,0,9
390 LOCATE 3,16:PRINT ";";STRING$(46,205);"
400 LOCATE 4,16:PRINT ";";STRING$(46,32);"
410 LOCATE 5,16:PRINT "PROGRAM TO INPUT DATA THAT DRIVES THE 
420 LOCATE 6,16:PRINT "SLAM SIMULATION PROGRAM 
430 LOCATE 7,16:PRINT ";";STRING$(46,32);"
440 LOCATE 8,16:PRINT ";";STRING$(46,205);"
450 LOCATE 10,16:PRINT "OPTIONS THAT ARE AVAILABLE : 
460 LOCATE 12,21:PRINT "1. ENTER A NEW SET OF PARTS DATA "

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470 LOCATE 14,21:PRINT "2. REVIEW AND ALTER EXISTING DATA"
480 LOCATE 16,21:PRINT "3. APPEND NEW DATA TO EXISTING ONE"
490 LOCATE 18,21:PRINT "4. PRINT THE DATA FROM EXISTING FILES"
500 LOCATE 20,21:PRINT "5. QUIT THE PROGRAM"
510 LOCATE 23,16:INPUT "ENTER CHOICE: ",CHO
520 IF CHO > 0 AND CHO < 6 THEN GOTO 550
530 SOUND 500,10:CHO=0
540 LOCATE 23,16:PRINT STRING*(50,32):GOTO 510
550 REM "CALLING THE SUBROUTINE FOR THE CHOICE MADE"
560 REM "******** **** ******************************************"
570 ON CHO GOTO 600,2440,5080,6330,590
580 GOTO 190
600 REM "**********************************************************"
610 REM * SUBROUTINE THAT ENTERS A SET OF NEW DATA *
620 REM "**********************************************************"
630 CLS:COLOR 27,0
640 LOCATE 4,30:PRINT "INSTRUCTIONS":COLOR 11,0
650 LOCATE 6,11:PRINT "YOU ARE REQUESTED TO INPUT THE PART DETAILS AND THE"
660 LOCATE 7,11:PRINT "OTHER DETAILS THAT ARE USED TO RUN THE SIMULATION"
670 LOCATE 8,11:PRINT "MODEL OF THE FLEXIBLE MANUFACTURING SYSTEM. THESE"
680 LOCATE 9,11:PRINT "DATA WILL BE ENTERED ON AN INTERACTIVE BASIS. PLEASE"
690 LOCATE 10,11:PRINT "RESPOND CAREFULLY TO THE QUERIES. FILES ARE CREATED"
700 LOCATE 11,11:PRINT "TO STORE THESE DATA. THE NAME FOR THESE FILES SHOULD"
710 LOCATE 12,11:PRINT "NOT BE GREATER THAN EIGHT CHARACTERS LONG. THESE FILE"
720 LOCATE 13,11:PRINT "NAMES WILL BE PROVIDED WITH AN APPEND DEPENDING ON THE"
730 LOCATE 14,11:PRINT "DATA CONTAINED IN THE FILE"
740 LOCATE 16,11:PRINT "FILE CONTAINING PART DETAILS----------[.PAR]"
750 LOCATE 17,11:PRINT "FILE CONTAINING PRIORITY DETAILS----------[.PRI]"
760 LOCATE 18,11:PRINT "FILE CONTAINING FIXTURE TYPE DETAILS----------[.FIX]"
770 LOCATE 19,11:PRINT "FILE CONTAINING SYSTEM LAYOUT DETAILS----------[.LAY]"
780 LOCATE 20,11:PRINT "FILE CONTAINING SPEED AND TRAVEL TIME DETAILS----[.TIM]"
790 COLOR 10,0:LOCATE 22,11:INPUT "ENTER NAME OF FILE TO STORE THE PART DETAILS: ",FILE1$
800 IF LEN(FILE1$) < 8 THEN GOTO 830
810 SOUND 500,10:FILE1$=" 
820 LOCATE 22,11:PRINT STRING*(68,32):GOTO 790
830 COLOR 30,0:LOCATE 25,11
840 PRINT "PRESS SPACE BAR TO CONTINUE"
850 IF INKEY$ < > " " THEN GOTO 850
860 PRO$=INKEY$
870 IF PRO$ < > " " THEN GOTO 860
880 FILE1$=FILE1$+".PAR"
890 OPEN FILE1$ FOR OUTPUT AS 11
900 CLS:COLOR 10,0:LOCATE 5,2
910 INPUT "TOTAL NUMBER OF PART TYPES TO BE PRODUCED: ",NPT
920 IF NPT < 25 THEN GOTO 970
930 LOCATE 7,2:COLOR 12,0:SOUND 500,20
940 PRINT "THE PROGRAM CAN HANDLE A MAXIMUM OF 25 PART TYPES ONLY"
950 FOR IL=1 TO 5000:NEXT IL
960 NPT=0:GOTO 900

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FOR I=1 TO NPT
FOR IQ=1 TO 220: PARR(I, IQ)=0: NEXT IQ
COLOR 10, 0: LOCATE 7, 2: PRINT "DATA FOR PART TYPE "; I
LOCATE 8, 2: PRINT "BATCH SIZE = "; NBS
LOCATE 9, 2: PRINT "NUMBER OF OPERATIONS = "; NOPS
PARR(I, 1)= I: PARR(I, 2)= NBS: PARR(I, 3)= NOPS
FOR K=1 TO NOPS
PRINT: PRINT "PROCESSING TIME FOR OPERATION "; K; " = ";
INPUT ": PARR(I, J1+1)
PRINT "FIXTURE TYPE FOR OPERATION "; K; " = ";
INPUT ": PARR(I, J1+1)
PRINT "POSSIBLE MACHINES FOR OPERATION "; K; " = ";
INPUT ": NALM
LJ=1
FOR L=J1+2 TO J1+NALM+1
PRINT "POSSIBILITY "; LJ; " = ";
INPUT ": PARR(I, LJ)
LJ=LJ+1
NEXT L
PRINT "TOOLS REQUIRED FOR OPERATION "; K; " = ";
INPUT ": NTOOL
LN=1
FOR M=J1+11 TO J1+NTOOL+10
PRINT "TOOL NUMBER "; LN; " = ";
INPUT ": PARR(I, LN)
LN=LN+1
NEXT M
NEXT K
REM ------------------------------
REM WRITING THE DATA ONTO THE FILES ON HARD DISK
REM ------------------------------
PRINT ": USING "; PARR(I, 3)
FOR JA=J1+2 TO 31+10
PRINT "; PARR(I, JA)
NEXT JA
FOR JAB=31+11 TO 31+20
PRINT "; PARR(I, JAB)
NEXT JAB
31=31+21
IF KT0T < 10 THEN GOTO 1340
A$= ": PRINT ", USING "; A$
1460 COLOR 30,0:LOCATE 25,14:PRINT "PRESS SPACE BAR TO CONTINUE"
1470 IF INKEY$ < > "" THEN GOTO 1470
1480 PRO*$=INKEY$
1490 IF PRO*$ < > " " THEN GOTO 1480
1500 CLS:NEXT 1
1510 CLOSE #1
1520 COLOR 11,0:LOCATE 9,16:PRINT STRING$(45,205)
1530 LOCATE 10,17:PRINT "DATA FOR ";NPT$" PART TYPE(S) HAVE BEEN ENTERED"
1540 LOCATE 11,16:PRINT STRING$(45,205):COLOR 30,0
1550 COLOR 30,0:LOCATE 25,14:PRINT "PRESS SPACE BAR TO CONTINUE"
1560 IF INKEY$ < > "" THEN GOTO 1560
1570 PRO*$=INKEY$
1580 IF PRO*$ < > " " THEN GOTO 1570
1590 REM ----------------------------------------
1600 REM CREATING THE FILE FOR THE PRIORITY DETAILS
1610 REM ----------------------------------------
1620 CLS:COLOR 10,0
1630 LOCATE 5,2:INPUT "ENTER FILE NAME FOR STORING PRIORITIES OF THE PART TYPES : ",FILE2$
1640 IF LEN(FILE2$) < = 8 THEN GOTO 1670
1650 SOUND 500,10:FILE2$=" 
1660 LOCATE 5,2:PRINT STRING$(70,32):GOTO 1630
1670 FILE2$=FILE2$+.PRI"
1680 FOR IJK=1 TO 25:JPRPT(IJK)=0:NEXT IJK
1690 PRINT:PRINT:PRINT
1700 OPEN FILE2$ FOR OUTPUT AS #1
1710 FOR IPM=1 TO NPT
1720 PRINT TAB(2);"ANY PRIORITY FOR PART TYPE ";IPM"[ 1-Yes, 2-No ]? ";
1730 INPUT *,IPR10R
1740 IF IPR10R=1 THEN JPRPT(IPM)=1
1750 NEXT IPM
1760 FOR IPP=1 TO NPT
1770 PRINT #1,USING *,###";IPP;":PRINT #1,USING *,###";JPRPT(IPP)
1780 NEXT IPP
1790 CLOSE #1
1800 COLOR 30,0
1810 LOCATE 25,14:PRINT "PRESS SPACE BAR TO CONTINUE"
1820 IF INKEY$ < > "" THEN GOTO 1820
1830 PRO*$=INKEY$
1840 IF PRO*$ < > " " THEN GOTO 1830
1850 REM ----------------------------------------
1860 REM FILE TO STORE LAYOUT DETAILS
1870 REM ----------------------------------------
1880 CLS:COLOR 10,0
1890 LOCATE 5,2:INPUT "ENTER FILE NAME TO STORE FMS LAYOUT DETAILS : ",FILE4$
1900 IF LEN(FILE4$) < = 8 THEN GOTO 1930
1910 SOUND 500,10:FILE4$=" 
1920 LOCATE 5,2:PRINT STRING$(70,32):GOTO 1890
1930 LOCATE 7,2:INPUT "NUMBER OF MACHINES IN THE SYSTEM = ",NMAC
1940 IF NMAC < = 9 THEN GOTO 1990
1950 SOUND 500,10:LOCATE 9,2:COLOR 12,0
1960 PRINT "THE PROGRAM CAN HANDLE A MAXIMUM OF 9 MACHINES ONLY*" : FOR IL=1 TO 5000:NEXT IL
1970 NMACH=0:LOCATE 7,2:PRINT STRING$(70,32):LOCATE 9,2:PRINT STRING$(70,32)
1980 COLOR 10,0:GOTO 1930
1990 FILE4$=FILE4$*.LAY*
2000 FOR ID=1 TO 9:DLOM(ID)=0:DULOM(ID)=0:STDM(ID)=0:ITRACK(ID)=0:NEXT ID
2010 OPEN FILE4$ FOR OUTPUT AS #1
2020 FOR NUM=1 TO NMACH
2030 PRINT;PRINT TAB(2);"THE LANE ON WHICH MACHINE ";NUM;" IS LOCATED = ";IN
2040 PRINT TAB(2);"DISTANCE BETWEEN LOADING STATION & MACHINE ";NUM;" [ mts ] = ";
2050 INPUT " ",DLOM(NUM)
2060 PRINT TAB(2);"DISTANCE BETWEEN MACHINE ";NUM;" & UNLOADING STATION [ mts ] = ";
2070 INPUT " ",DULOM(NUM)
2080 PRINT TAB(2);"DISTANCE BETWEEN TOOL CRIB AND THE MACHINE ";NUM;" [ mts ] = ";
2090 INPUT " ",STDM(NUM)
2100 PRINT #1, USING " ";NUM;:PRINT #1, USING " ";ITRACK(NUM);:PRINT #1, USING " ";DLOM(NUM);
2110 PRINT #1, USING " ";DULOM(NUM);:PRINT #1, USING " ";STDM(NUM)
2120 NEXT NUM
2130 CLOSE #1
2140 PRINT;PRINT
2150 COLOR 30,0:LOCATE 25,14:PRINT "PRESS SPACE BAR TO CONTINUE"  
2160 IF INKEYS < > "" THEN GOTO 2160
2170 PRO%=INKEYS
2180 IF PRO% < > " " THEN GOTO 2170
2190 REM ---------------------------------------------
2200 REM FILE TO STORE TIME AND SPEED DETAILS
2210 REM ---------------------------------------------
2220 CLS;COLOR 10,0
2230 LOCATE 5,2;INPUT "ENTER FILE NAME TO STORE TIME AND SPEED DETAILS OF THE MHS: ";FILE5$
2240 IF LEN(FILE5$) < = 8 THEN GOTO 2270
2250 SOUND 500,10:FILE5$=FILE5$*
2260 LOCATE 5,2:PRINT STRING$(70,32):GOTO 2230
2270 FILE5%=FILE5$*.TIM*
2280 OPEN FILE5% FOR OUTPUT AS #1
2290 LOCATE 8,2;INPUT "ENTER SPEED OF THE LOADING AGV [ mts/min ] = ";SPAGV
2300 LOCATE 9,2;INPUT "ENTER SPEED OF THE UNLOADING AGV [ mts/min ] = ";SPUAGV
2310 LOCATE 10,2;INPUT "ENTER SPEED OF THE TOOL CONVEYOR [ mts/min ] = ";SPCON
2320 LOCATE 11,2;INPUT "ENTER TRAVEL TIME FOR THE LOADING CRANE [ mins ] = ";TTCSLO
2330 LOCATE 12,2;INPUT "ENTER TRAVEL TIME FOR THE UNLOADING CRANE [ mins ] = ";TTCSU
2340 PRINT #1, USING " ";SPAGV;PRINT #1, USING " ";SPUAGV;PRINT #1, USING " ";SPCON;
2350 PRINT #1, USING " ";TTCSLO;PRINT #1, USING " ";TTCSU;
2360 CLOSE #1
2370 COLOR 30,0
2380 LOCATE 21,14:PRINT "PRESS SPACE BAR TO RETURN" 
2390 LOCATE 22,14:PRINT "TO THE MAIN MENU"
2400 IF INKEYS < > "" THEN GOTO 2400
2410 PRO% = INKEYS
2420 IF PRO% < > " " THEN GOTO 2410

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2430 GOTO 350
2440 REM ************************************************************
2450 REM ** SUBROUTINE TO REVIEW AND ALTER THE EXISTING DATA **
2460 REM ************************************************************
2470 CLS:COLOR 10,0;LOCATE 5,16:PRINT "OPTIONS THAT ARE AVAILABLE ;
2480 LOCATE 7,21:PRINT "1. PART TYPE DETAILS"
2490 LOCATE 9,21:PRINT "2. PART TYPE PRIORITIES"
2500 LOCATE 11,21:PRINT "3. LAYOUT DETAILS"
2510 LOCATE 13,21:PRINT "4. TIME AND SPEED DETAILS"
2520 LOCATE 15,21:PRINT "5. QUIT THIS SEGMENT"
2530 LOCATE 18,16:INPUT "ENTER YOUR CHOICE :  ",CHOI
2540 IF CHOI > 0 OR CHOI < 6 THEN GOTO 2570
2550 SOUND 500,10;CHOI=0
2560 LOCATE 18,16:PRINT STRING*(150,32):GOTO 2530
2570 ON CHOI GOTO 2590,3910,4260,4720,350
2580 REM
2590 REM SUBROUTINE TO REVIEW PART DETAILS
2600 REM
2610 IREC=0
2620 CLS:COLOR 11,0:LOCATE 5,2:PRINT "FILE(S) THAT CONTAIN PART TYPE DETAILS .  ..FILES C:\PAR%
2630 OPEN FILE1* FOR INPUT AS 11
2640 INPUT I1,PARR(IREC,1),PARR(IREC,2),PARR(IREC,3)
2650 FOR K=1 TO 10
2660 J1=4+(K-1)*21
2670 INPUT I1,PARR(IREC,J1),PARR(IREC,J1+1)
2680 FOR JA=J1+2 TO J1+10:INPUT I1,PARR(IREC,JA)
2690 FOR JAB=J1+11 TO J1+20:INPUT I1,PARR(IREC,JAB)
2700 NEXT K
2710 NTPT=IREC-1
2720 IF IPA > 25 THEN GOTO 2810
2730 FOR KL=1 TO 3000:NEXT KL
2740 IF PARR(IPA,1) > 0! THEN GOTO 2840
2750 LOCATE 7,2;COLOR 12,0;PRINT "ENTER THE OPERATION NUMBER OF PART TYPE ";IPA;
2760 FOR K=1 TO 3000:NEXT K
2770 IF IPA > 25 THEN GOTO 2810
2780 IF PARR(IPA,1) > 0! THEN GOTO 2840
2790 IF IPA > 25 THEN GOTO 2810
2800 LOCATE 7,2;COLOR 12,0;PRINT "ENTER THE OPERATION NUMBER OF PART TYPE ";IPA;
2810 FOR K=1 TO 3000:NEXT K
2820 IF IPA > 25 THEN GOTO 2810
2830 IF IPA > 25 THEN GOTO 2810
2840 LOCATE 7,2;COLOR 12,0;PRINT "ENTER THE OPERATION NUMBER OF PART TYPE ";IPA;
2850 IF IPA > 25 THEN GOTO 2810
2860 IF IPA > 25 THEN GOTO 2810
2870 IF IPA > 25 THEN GOTO 2810
2900 PRINT TAB(2);"------------------------";
2910 PRINT TAB(6); INDE+1;" . PROCESSING TIME ------- ";PARR(IPA,J11)
2920 IFTY=PARR(IPA,J11+1);PRINT TAB(6); INDE+2;" . FIXTURE TYPE ------- ";IFTY
2930 PRINT TAB(6); INDE+3;" . ALTERNATE MACHINES -- ";
2940 ICDE=0
2950 FOR JAY=J11+2 TO J11+10
2960 ICDE=ICDE+1
2970 IALMAC=PARR(IPA,JAY); IF IALMAC = 0 THEN GOTO 3020
2980 IF ICDE > 1 THEN GOTO 3000
2990 PRINT IALMAC;:GOTO 3010
3000 PRINT "or";IALMAC;
3010 NEXT JAY
3020 PRINT
3030 PRINT TAB(6); INDE+4;" . TOOLS REQUIRED ------ ";
3040 ICTA=0
3050 FOR JAT=J11+11 TO J11+20
3060 ICTA=ICTA+1
3070 IALTO=PARR(IPA,JAT); IF IALTO = 0 THEN GOTO 3120
3080 IF ICTA > 1 THEN GOTO 3100
3090 PRINT IALTO;:GOTO 3110
3100 PRINT ",";IALTO;
3110 NEXT JAT
3120 PRINT
3130 LABS=PARR(IPA,2)
3140 PRINT TAB(6); INDE+5;" . BATCH SIZE ---------- ";LABS
3150 COLOR 10,0;LOCATE 18,2;INPUT "ANY CHANGES TO BE MADE [ Y-Yes, N-No ] ? ",AN$ 
3160 IF AN$="Y" OR AN$="y" THEN GOTO 3210
3170 IF AN$="N" OR AN$="n" THEN GOTO 3610
3180 SOUND 500,10:AN$=" 
3190 LOCATE 18,2;PRINT STRING$(50,32):GOTO 3150
3200 REM ------------------------
3210 REM CHANGING THE DATA
3220 REM ------------------------
3230 LOCATE 19,2;INPUT "ENTER YOUR CHOICE [ Number before each line ] ": ",CH02
3240 ON CH02 GOTO 3270,3310,3350,3450,3550
3250 SOUND 500,10:CH02=0
3260 LOCATE 19,2;PRINT STRING$(70,32):GOTO 3230
3270 REM ------------------------
3280 REM NEW PROCESSING TIME
3290 REM ------------------------
3300 CLS;LOCATE 22,2;PRINT "NEW PROCESSING TIME FOR OPERATION ",LNOP;" OF PART TYPE ";IPA;" = ";
3310 INPUT ",PR1=PARR(IPA,J11)=PR1;CLS;GOTO 2850
3320 REM ------------------------
3330 REM NEW FIXTURE TYPE
3340 CLS;LOCATE 22,2;PRINT "NEW FIXTURE TYPE FOR OPERATION ",LNOP;" OF PART TYPE ";IPA;" = ";
3350 REM ------------------------
3360 REM NEW MACHINES
3370 REM ------------------------
3380 CLS:LOCATE 5,2
3390 FOR IMT=J11+2 TO J11+10:PARR(IPA,IMT)=0!:NEXT IMT
3400 PRINT "POSSIBLE MACHINES FOR OPERATION ";LNOP," OF PART TYPE ";IPA,"= ";:INPUT " ",NAM
3410 FOR IAL2=1 TO NAM
3420 PRINT TAB(36);"POSSIBILITY ";IAL2;" = ";:INPUT " ",IM1:PARR(IPA,J11+IAL2+1)=IM1
3430 NEXT IAL2
3440 CLS:GOTO 2850
3450 REM ----------------
3460 REM NEW TOOLS
3470 REM ----------------
3480 CLS:LOCATE 5,2
3490 FOR IMG=J11+11 TO J11+20:PARR(IPA,IMG)=0!:NEXT IMG
3500 PRINT "TOOLS REQUIRED FOR OPERATION ";LNOP," OF PART TYPE ";IPA,"= ";:INPUT " ",NTOOL
3510 FOR IALT1=1 TO NTOOL
3520 PRINT TAB(36);"TOOL NUMBER ";IALT1;" = ";:INPUT " ",IT1:PARR(IPA,J11+IALT1+10)=IT1
3530 NEXT IALT1
3540 CLS:GOTO 2850
3550 REM ----------------
3560 REM NEW BATCH SIZE
3570 REM ----------------
3580 CLS:LOCATE 22,2:PRINT "NEW BATCH SIZE FOR PART TYPE ";IPA,"= ";
3590 INPUT ":,NB1;PARR(IPA,2)=NB1:CLS:GOTO 2850
3600 REM ----------------
3610 REM CHECK TO PROCEED FURTHER
3620 REM ----------------
3630 LOCATE 19,2:INPUT "ANY OTHER PART DETAIL TO BE REVIEWED [ Y-Yes, N-No ] ? ",AN$ 
3640 IF AN$="Y" OR AN$="y" THEN GOTO 2780
3650 IF AN$="N" OR AN$="n" THEN GOTO 3690
3660 SOUND 500,10:AN$=" 
3670 LOCATE 19,2:PRINT STRINGS(70,32):GOTO 3630
3680 REM ----------------
3690 REM PUTTING BACK THE DETAILS IN THEIR FILES
3700 REM ----------------
3710 OPEN FILE1* FOR OUTPUT AS 
3720 FOR IPR=1 TO 25
3730 IF PARR(IPR,1) = 0! THEN GOTO 3890
3740 PRINT ",USING ";PARR(IPR,1);PRINT ",USING ";PARR(IPR,2);PRINT ",USING ";PARR(IPR,3)
3750 J1=4:KTOT=0
3760 KTOT=KTOT+1
3770 PRINT ",USING ";PARR(IPR,J1)
3780 PRINT ",USING ";PARR(IPR,J1+1)
3790 FOR JA=J1+2 TO J1+10
3800 PRINT ",USING ";PARR(IPR,JA)
3810 NEXT JA
3820 FOR JAB=J1+11 TO J1+20
3830 PRINT ",USING ";PARR(IPR,JAB)
3840 NEXT JAB
3850 J1=J1+21
3860 IF KTOT < 10 THEN GOTO 3760

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3870   A$="":PRINT 1, USING "\"":A$
3880   NEXT IPR
3890   CLOSE #1
3900   GOTO 2440
3910   REM SUBROUTINE TO REVIEW PRIORITY DETAILS
3920   REM ---------------------------------------------------------------
3930   CLS: COLOR 11,0:LOCATE 5,2:PRINT "FILE(S) THAT CONTAIN PRIORITY DETAILS FOR VARIOUS PART TYPES:");FILES "C:\PRI"
3940   COLOR 10,0:PRINT:PRINT TAB(2);"ENTER NAME OF FILE CONTAINING PRIORITY DETAILS: ";:INPUT "
3950   FILE2$:FILE2$=FILE2$+.PRI"
3960   IPRIOR=0:FOR IPG=1 TO 25; JPRPT(IPG)=0: NEXT IPG
3970   OPEN FILE2$ FOR INPUT AS #1
3980   IF EOF(1) THEN GOTO 4010
3990   INPUT #1,IPX,JPRPT(IPRIOR)
4000   GOTO 3980
4010   CLOSE #1
4020   CLS: COLOR 11,0:LOCATE 5,2:PRINT "PRIORITY DETAILS FOR THE PART TYPES:
4030   LOCATE 6,2:PRINT "----------------------------------------------------------"
4040   FOR IPM=1 TO IPRIOR-1
4050 IF JPRPT(IPM) = 1 THEN PRNT$="YES" ELSE PRNT$="NO"
4060 PRINT TAB(6);IPM;" PRIORITY FOR PART TYPE ";IPM;"— ";PRNT$;
4070   NEXT IPM
4080   COLOR 10,0:LOCATE 22,2:PRINT "ANY CHANGES TO BE MADE? [Y-YES, N-NO] ";,ANS$
4090 IF ANS$="Y" OR ANS$="y" THEN GOTO 4130
4100 IF ANS$="N" OR ANS$="n" THEN GOTO 4200
4110 SOUND 500,10:ANS$=" 
4120 LOCATE 22,2:PRINT STRING$(70,32);GOTO 4080
4130 LOCATE 23,2:PRINT "ENTER YOUR CHOICE [Number before each line]: ";,ICH03
4140 IF ICH03 > 0 AND ICH03 < IPRIOR THEN GOTO 4170
4150 SOUND 500,10:ICH03=0
4160 LOCATE 23,2:PRINT STRING$(70,32);GOTO 4130
4170   CLS:LOCATE 22,2:PRINT "NEW PRIORITY FOR PART TYPE [1-YES, 2-NO]: ";ICH03;" = "
JPRPT(ICH03)
4180 IF JPRPT(ICH03) = 1 OR JPRPT(ICH03) = 2 THEN GOTO 4020
4190 PRINT TAB(6):PRINT STRING$(70,32);GOTO 4170
4200 OPEN FILE2$ FOR OUTPUT AS #1
4210 FOR IPT=1 TO IPRIOR-1
4220 PRINT #1, USING "###";IPT;:PRINT #1, USING "###";JPRPT(IPT)
4230 NEXT IPT
4240 CLOSE #1
4250 GOTO 2440
4260 REM SUBROUTINE FOR REVIEWING LAYOUT DETAILS
4270 REM ---------------------------------------------------------------
4280 REM ---------------------------------------------------------------
4290 CLS:COLOR 11,0:LOCATE 5,2:PRINT "FILE(S) THAT CONTAIN THE FMS LAYOUT DETAILS:");FILES "C:\LAY"
4300 COLOR 10,0:PRINT:PRINT TAB(2);"ENTER THE NAME OF THE FILE THAT CONTAINS THE LAYOUT DETAILS:
4310 INPUT ";FILE4$:FILE4$=FILE4$+.LAY"
4320 INC=0:FOR IMB=1 TO 9;DLOM(IMB)=0;DULOM(IMB)=0;STM(IMB)=0;ITRACK(IMB)=0:NEXT IMB

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4320 OPEN FILE4$ FOR INPUT AS #1
4330 IMC=IMC+1:IF EOF(1) THEN GOTO 4360
4340 INPUT #1,NUM,ITRACK(IMC),DLOM(IMC),DULOM(IMC),DSTM(IMC)
4350 GOTO 4330
4360 CLOSE #1
4370 CLS:LOCATE 5,2;COLOR 10,0;PRINT "ENTER THE MACHINE WHOSE LAYOUT DETAIL YOU WANT TO REFER TO :");INPUT "",MAC
4380 TM=IMC-1
4390 IF MAC > 0 AND MAC < TM+1 THEN GOTO 4420
4400 SOUND 500,10:MAC=0
4410 COLOR 12,0:LOCATE 7,2:PRINT "SYSTEM HAS ONLY ";IMC-1:" MACHINES - TRY AGAIN":FOR KL = 1 TO 3
4420 COLOR 11,0:LOCATE 7,2:PRINT "1. THE LANE ON WHICH MACHINE ";MAC;" IS LOCATED -------- ";I
4430 LOCATE 9,2:PRINT "2. DISTANCE BETWEEN MACHINE ";MAC;" AND LOADING STATION -- ";DLOM(MAC)
4440 LOCATE 9,2:PRINT "3. DISTANCE BETWEEN MACHINE ";MAC;" AND UNLOADING STATION ---- ";DULOM(MAC)
4450 LOCATE 10,2:PRINT "4. DISTANCE BETWEEN MACHINE ";MAC;" AND TOOL CRIB ------- ";DSTM(MAC)
4460 COLOR 10,0:LOCATE 15,2:INPUT "ANY CHANGES TO BE MADE [ Y-Yes, N-No ] ? ";AN$
4470 IF AN$="Y" OR AN$="y" THEN GOTO 4510
4480 IF AN$="N" OR AN$="n" THEN GOTO 4600
4490 SOUND 500,10:AN$=" 
4500 LOCATE 15,2:PRINT STRING$(50,32): GOTO 4460
4510 LOCATE 16,2:PRINT "ENTER YOUR CHOICE [ Number before each line ] : ";IM01
4520 IF IM01 > 0 AND IM01 < 5 THEN GOTO 4550
4530 SOUND 500,10:IM01=0
4540 LOCATE 16,2:PRINT STRING$(70,32):GOTO 4500
4550 ON IM01 GOTO 4560,4570,4580,4590
4560 CLS:LOCATE 20,2:PRINT "THE NEW LANE ON WHICH MACHINE ";MAC;" IS LOCATED = ";;INPUT " ",ITRAC
4570 CLS:LOCATE 20,2:PRINT "NEW DISTANCE BETWEEN MACHINE ";MAC;" AND LOADING STATION = ";;INPUT " ",DLOM(MAC):CLS:GOTO 4420
4580 CLS:LOCATE 20,2:PRINT "NEW DISTANCE BETWEEN MACHINE ";MAC;" AND UNLOADING STATION = ";;INPUT " ",DULOM(MAC):CLS:GOTO 4420
4590 CLS:LOCATE 20,2:PRINT "NEW DISTANCE BETWEEN MACHINE ";MAC;" AND THE CENTRAL TOOL STORAGE = ";;INPUT ";DSTM(MAC):CLS:GOTO 4420
4600 LOCATE 16,2:INPUT "ANY MORE MACHINE LAYOUT DETAILS TO BE REVIEWED [ Y-Yes , N-No ] ? ";,AN$
4610 IF AN$="Y" OR AN$="y" THEN GOTO 4370
4620 IF AN$="N" OR AN$="n" THEN GOTO 4650
4630 SOUND 500,10:AN$=" 
4640 LOCATE 16,2:PRINT STRING$(70,32):GOTO 4600
4650 OPEN FILE4$ FOR OUTPUT AS #1
4660 FOR NMA=1 TO IMC-1
4670 PRINT #1,USING ";###";NMA;":PRINT #1,USING ";###";ITRACK(NMA);":PRINT #1,USING ";###.";DLOM(NMA);":PRINT #1,USING ";###.";DULOM(NMA);":PRINT #1,USING ";###.";DSTM(NMA)
4680 NEXT NMA
4690 CLOSE #1
4700 GOTO 4440
4710 REM  SUBROUTINE TO CHANGE THE SPEED AND TIME DETAILS OF THE MHS

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4740 REM -------------------------------
4750 CLS:COLOR 11,0;LOCATE 5,2:PRINT "FILE(S) THAT CONTAIN TIME AND SPEED DETAILS OF THE MHS :":FILES "C:\.TIM"
4760 COLOR 10,0;PRINT:PRINT TAB(2);:INPUT "ENTER NAME OF FILE THAT CONTAINS THE SPEED DETAILS : ":FILES$=FILES$+ ".TIM"
4770 OPEN FILES$ FOR INPUT AS 1
4780 INPUT 1,SPAGV,SPUAGV,SPCON,TTSLD,TTULSO
4790 CLOSE 1
4800 CLS:COLOR 11,0
4810 LOCATE 5,2:PRINT "FILE(S) THAT CONTAIN TIME AND SPEED DETAILS OF THE MHS :":FILES$=FILES$+ ".TIM"
4820 LOCATE 6,2:PRINT "SPEED AND TRAVEL TIME DETAILS OF THE MHS :":FILES$=FILES$+ ".TIM"
4830 LOCATE 8,2:PRIN T "1. SPEED OF THE LOADING AGV ------------------ ":SPAGV; [ats/min]
4840 LOCATE 9,2:PRINT "2. SPEED OF THE UNLOADING AGV ------------------ ":SPUAGV; [ats/min]
4850 LOCATE 10,2:PRINT "3. SPEED OF THE TOOL CONVEYOR ------------------ ":SPCON; [ats/min]
4860 LOCATE 11,2:PRINT "4. TRAVEL TIME FOR THE LOADING CRANE ------ ":TTSLD; [mins]
4870 LOCATE 12,2:PRINT "5. TRAVEL TIME FOR THE UNLOADING CRANE ----- ":TTULSO; [mins]
4880 COLOR 10,0:LOCATE 15,2:INPUT "ANY CHANGES TO BE MADE [ Y-Yes, N-No ] ? ":AN$
4890 IF AN$="Y" OR AN$="y" THEN GOTO 4930
4900 IF AN$="N" OR AN$="n" THEN GOTO 5030
4910 SOUND 500,10;AN$=" 
4920 LOCATE 15,2:PRINT STRING$(70,32);GOTO 4880
4930 LOCATE 16,2:INPUT "ENTER YOUR CHOICE [ Number before each line ] : ":ISP1
4940 IF ISP1 > 0 AND ISP1 < 6 THEN GOTO 4970
4950 SOUND 500,10;ISP1=0
4960 LOCATE 16,2:PRINT STRING$(70,32);GOTO 4930
4970 ON ISP1 GOTO 4980,4990,5000,5010,5020
4980 CLS:LOCATE 20,2:INPUT "NEW SPEED OF LOADING AGV [ mts/min ] = ":,SPAGV:GOTO 4800
4990 CLS:LOCATE 20,2:INPUT "NEW SPEED OF THE UNLOADING AGV [ mts/min ] = ":,SPUAGV:GOTO 4800
5000 CLS:LOCATE 20,2:INPUT "NEW SPEED OF THE TOOL CONVEYOR [ mts/min ] = ":,SPCON:GOTO 4800
5010 CLS:LOCATE 20,2:INPUT "NEW TRAVEL TIME FOR THE LOADING CRANE [ mins ] = ":,TTSLD:GOTO 4800
5020 CLS:LOCATE 20,2:INPUT "NEW TRAVEL TIME FOR THE UNLOADING CRANE [ mins ] = ":,TTULSO:GOTO 4800
5030 OPEN FILES$ FOR OUTPUT AS 1
5040 PRINT 1,USING " 
5050 PRINT 1,USING " 
5060 CLOSE 1
5070 GOTO 4240
5080 REM "SUBROUTINE TO APPEND DATA TO THE EXISTING FILES 
5090 REM "SUBROUTINE TO APPEND DATA TO THE EXISTING FILES 
5100 REM "SUBROUTINE TO APPEND DATA TO THE EXISTING FILES 
5110 CLS:LOCATE 7,16:COLOR 10,0;PRINT "OPTIONS THAT ARE AVAILABLE : ":
5120 LOCATE 10,2:PRINT "1. ADD ANOTHER PART TYPE"
5130 LOCATE 12,2:PRINT "2. ADD ANOTHER MACHINE 
5140 LOCATE 14,2:PRINT "3. QUIT THIS SEGMENT" 
5150 LOCATE 17,16:INPUT "ENTER YOUR CHOICE : ":CHO4
5160 IF CHO4 > 0 OR CHO4 < 4 THEN GOTO 5190
5170 SOUND 500,10;CHO4=0
5180 LOCATE 17,16:PRINT STRING$(70,32):GOTO 5150
5190 ON CHO4 GOTO 5200,5980,350
5200 REM ---------------------------------------------

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5210 REM ROUTINE TO APPEND PART TYPE
5220 REM -----------------------------
5230 CLS:LOCATE 5,2;COLOR 11,0;PRINT "FILE(S) THAT CONTAIN PART TYPE DETAILS : ";FILES "C:1.PAR"
5240 COLOR 10,0;PRINT:PRINT TAB(2):;INPUT "ENTER NAME OF FILE THAT CONTAINS PART TYPE DETAILS : ",FILE1$;FILE1$=FILE1*$".PAR"
5250 CLS:COLOR 11,0:LOCATE 5,2;PRINT "FILE(S) THAT CONTAIN PRIORITY DETAILS : ";FILES "C:*.*PRI"
5260 COLOR 10,0:PRINT:PRINT TAB(2);:INPUT "ENTER NAME OF FILE THAT CONTAINS PRIORITY DETAILS : ",FILE2$:FILE2$=FILE2*$".PRI"
5270 IREC=0;IPRIOR=0
5280 OPEN FILE1$ FOR INPUT AS 1
5290 IREC=IREC+1;Ktot=0;IF EOF(1) THEN GOTO 5390
5300 FOR INY=1 TO 220:PARR(IREC,INY)=0!:NEXT INY
5310 INPUT #1,PARR(IREC,1),PARR(IREC,2),PARR(IREC,3)
5320 FOR K=1 TO 10
5330 J11=4+(K-1)*21
5340 INPUT #1,PARR(IREC,J11),PARR(IREC,J11+1)
5350 FOR JA=J11+2 TO J11+10:INPUT #1,PARR(IREC,JA):NEXT JA
5360 FOR JAB=J11+11 TO J11+20:INPUT #1,PARR(IREC,JAB):NEXT JAB
5370 NEXT K
5380 GOTO 5290
5390 NTPT=IREC
5400 CLOSE 1
5410 FOR JHY=1 TO 25:JPRPT(JHY)=0:NEXT JHY
5420 OPEN FILE2$ FOR INPUT AS 2
5430 IPRIOR=IPRIOR+1:IF EOF(2) THEN GOTO 5460
5440 INPUT #2,IP,JPRPT(IPRIOR)
5450 GOTO 5430
5460 CLOSE 2
5470 NPTY=IPRIOR
5480 OPEN FILE1$ FOR APPEND AS 1
5490 L1=1:M1=1
5500 FOR IND=1 TO 220:PARR(NTPT,IND)=0!:NEXT IND
5510 CLS:COLOR 10,0:LOCATE 7,2;PRINT "DATA FOR PART TYPE ";NTPT
FOR M=J1+11 TO J1+NTPT+10
PRINT TAB(20);"TOOL NUMBER ";LN=LN+1
NEXT M
M1=M1+10
NEXT K
PRINT #1,USING "##.##";PARR(NPTY,1);PRINT #1,USING "##.##";PARR(NPTY,2);PRINT #1,USING "##.##";PARR(NPTY,3);
J3=4:KTOT=0
PRINT #1,USING "##.##";PARR(NPTY,J3);
PRINT #1,USING "##.##";PARR(NPTY,J3+1);
FOR JA=J3+2 TO J3+10:PRINT #1,USING "##.##";PARR(NPTY,JA):NEXT JA
FOR JAB=J3+11 TO J3+20:PRINT #1,USING "##.##";PARR(NPTY,JAB):NEXT JAB
J3=J3+21
IF KTOT < 10 THEN GOTO 5770
A$="":PRINT #1,USING "##.##";A$ IF IPR0=1 THEN JPRPT(NPTY)=1
PRINT #2,USING "##.##";JPRPT(NPTY)
PRINT #1;PRINT T A B (2);:INPUT "ANY MORE ADDITIONS [ Y-Yes, N-No ] ? ",AN$ IF AN$="Y" OR AN$="y" THEN GOTO 5930
IF AN$="N" OR AN$="n" THEN GOTO 5940
NPTY=NPTY+1:NTPT=NTPT+1:GOTO 5490
CLOSE #1
COLOR 11,0:LOCATE 10,16;PRINT "SORRY, BUT THE SIMULATI0N MODEL CAN ONLY ALLOW A 
MAXIMUM OF NINE MACHINES. YOU ARE EXCEEDING THE 
LIMITS OF THE SIMULATI0N MODEL. 
PRESS SPACE BAR TO CONTINUE 
COLOR 11,0:LOCATE 22,14
PRINT "P R E S S  S P A C E  B A R  T O  C O N T I N U E "

COLOR 11,0:LOCATE 5,2;PRINT "FILE(S) THAT CONTAIN THE FMS LAYOUT DETAILS : ";FILES "C:\LAY"
COLOR 10,0:PRINT TAB(2);:INPUT "ENTER NAME OF FILE THAT CONTAINS THE FMS LAYOUT DETAILS : ":FILES "FILE4\LAY"
ILA=0
FOR MA=1 TO 9:DULOM(MA)=0:DLOM(MA)=0:DSTM(MA)=0:ITRACK(MA)=0:NEXT MA
OPEN FILE4 FOR INPUT AS #1
ILAILA+1:IF EOF(1) THEN GOTO 6080
INPUT #1,ILT,ITRACK(ILA),DLOM(ILA),DULOM(ILA),DSTM(ILA)
GOTO 6050
CLOSE #1
COLOR 11,0
COLOR 11,0
PRINT "SORRY, BUT THE SIMULATI0N MODEL CAN ONLY ALLOW A 
MAXIMUM OF NINE MACHINES. YOU ARE EXCEEDING THE 
LIMITS OF THE SIMULATI0N MODEL. 
PRESS SPACE BAR TO CONTINUE 
COLOR 30,0:LOCATE 22,14
PRINT "P R E S S  S P A C E  B A R  T O  C O N T I N U E "
COLOR 11,0
COLOR 11,0
COLOR 11,0
COLOR 11,0
IF INKEY$ < > "" THEN GOTO 6150
PRO$=INKEY$
IF PRO$ < > "" THEN GOTO 6160
OPEN FILEE$ FOR APPEND AS #1
CLS:COLOR 11:LOCATE 5,2:PRINT "LAYOUT DETAILS FOR MACHINE ";ILA
LOCATE 6,2:PRINT "------------------------"
COLOR 10,0:LOCATE 9,2:PRINT "THE LANE ON WHICH MACHINE ";ILA;" IS LOCATED = ";INPUT ":",ITRACK(ILA)
LOCATE 12,2:PRINT "DISTANCE BETWEEN MACHINE ";ILA;" AND THE LOADING STATION = ";INPUT ":",DLOM(ILA)
LOCATE 13,2:PRINT "DISTANCE BETWEEN MACHINE ";ILA;" AND UNLOADING STATION = ";INPUT ":",DULOM(ILA)
LOCATE 14,2:PRINT "DISTANCE BETWEEN MACHINE ";ILA;" AND THE TOOL STORAGE = ";INPUT ":",DSTM(ILA)
PRINT #1,USING "###";ILA;:PRINT #1,USING "##";ITRACK(ILA);:PRINT #1,USING "###";DLOM(ILA);:PRINT #1,USING "###";DULOM(ILA);:PRINT #1,USING "###";DSTM(ILA)
REM ********************* **********
REM * SUBROUTINE TO PRINT OUT PART DETAILS *
REM ********************* **********
CLS:COLOR 11:LOCATE 5,2:PRINT "FILE(S) THAT CONTAIN PART TYPE DETAILS :  ";FILES "C:*.PAR"
PRINT:COLOR 10,0
PRINT TAB(2);"ENTER NAME OF FILE CONTAINING PART TYPE DETAILS :  ";INPUT ":",FILE1*:FILE1$=FILE1*+.PAR
IREC=0
OPEN FILE1$ FOR INPUT AS #1
IREC=IREC+1:KOT=0:IF EOF(1) THEN GOTO 6520
FOR INR=1 TO 220:PARR(IREC,INR)=0!:NEXT INR
FOR K=1 TO 10
J4=4+(K-1)*21
INPUT ":",PARR(IREC,J4)
INPUT ":",PARR(IREC,J4+1)
FOR JA=J4+2 TO J4+10:INPUT ":",PARR(IREC,JA):NEXT JA
FOR JAB=J4+11 TO J4+20:INPUT ":",PARR(IREC,JAB):NEXT JAB
NEXT K
GOTO 6410
NTPT=IREC-1
CLOSE #1:CLOSE #3
CLS:COLOR 11,0
SOUND 500,20:LOCATE 11,21:PRINT "PLEASE SWITCH ON THE LINE PRINTER"
LOCATE 15,21:PRINT "POSITION THE PAPER IN THE PRINTER"
LOCATE 22,14:COLOR 30,0:PRINT "PRESS SPACE BAR TO CONTINUE"
IF INKEY$ < > "" THEN GOTO 6580
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6590 PRINT INKEY$
6600 IF PROS < > * THEN GOTO 6590
6610 CLS:COLOR 11,0:LOCATE 13,20:PRINT "PRINTING OF PART TYPE DETAILS IN PROGRESS"
6620 LPRINT: LPRINT CHR$(27)CHR$(15);:WIDTH "LPT1"; 132
6630 LPRINT TAB(11);"PART TYPE DETAILS"
6640 LPRINT TAB(11);
6650 LPRINT TAB(11);"| Part | Batch | Opn | Proc. | FT | Machine(s) |
"Tools required |
6660 LPRINT TAB(11);"| Type | Size | No. | Time |
"|
6670 FOR LN=1 TO NTPT
6680 IF PARR(LN,1)=0! THEN GOTO 7080
6690 LPRINT TAB(11);"|TAB(13);LN;
6700 LABS=PARR(LN,2);LPRINT TAB(16);"|TAB(21);LABS;
6710 LNP= PARR(LN,3);J11=4;J21=1
6720 FOR MN2=1 TO LNP
6730 LPRINT TAB(11);"| JMN2 ;
6740 LPRINT USING "# #.##";PARR(LN,JMN2);"|IFTY=PARR(LN,JMN2+1);LPRINT TAB(46);IFTY;
6750 NEXT MN2
6760 ICODE=0
6770 FOR JA=J11+2 TO J11+10:IALMAC=PARR(LN,JA)
6780 ICDE=ICDE+1
6790 IF IALMAC=0 THEN GOTO 6860
6800 IF ICDE > 1 THEN GOTO 6840
6810 LPRINT USING "##";IALMAC;GOTO 6850
6820 LPRINT USING "or##";IALMAC;
6830 NEXT JA
6840 LPRINT TAB(79);"
6850 LPRINT TAB(11);"| ";
6860 IFTA=0
6870 FOR JAB=J11+11 TO J11+20:IALTO=PARR(LN, JAB)
6880 ICTA=ICTA+1
6890 IF IALTO=0 THEN GOTO 6950
6900 IF ICTA > 1 THEN GOTO 6930
6910 LPRINT USING "##";IALTO;GOTO 6940
6920 LPRINT USING "##";IALTO;
6930 NEXT JAB
6940 LPRINT TAB(112);"|J11=J11+21;J21=J21+1
6950 LPRINT TAB(11);"| ";
6960 IF JMN2=LNP THEN GOTO 6980
6970 LPRINT TAB(11);"
6980 NEXT MN2
6990 IF LN=NTPT THEN GOTO 7010
7000 LPRINT TAB(11);"
7010 NEXT LN
7020 LPRINT TAB(11);"
7030 LOCATE 22,14:COLOR 30,0:PRINT "PRESS SPACE BAR TO CONTINUE"
7040 IF INKEY$ < > "" THEN GOTO 7040
7050 PRO%=INKEY$
7060 IF PRO% < > • THEN GOTO 7060
7070 FOR I=1 TO 5:LPINT: NEXT I
7080 CLS:LOCATE 5,2;COLOR 11,0:PRINT "FILE(S) THAT CONTAIN PRIORITY DETAILS : C:
7090 COLOR 10,0:PRINT:PRINT TAB(2);"ENTER FILE NAME CONTAINING PRIORITY DETAILS :";INPUT ", File2$=FILE2$+.PRI"
7100 CLS:LOCATE 13,20:COLOR 11,0:PRINT "PRINTING OF PRIORITY DETAILS IN PROGRESS"
7110 IPRIOR=0:FOR JH=1 TO 25:JPRPT(JH)=0: NEXT JH
7120 OPEN FILE2$ FOR INPUT AS #1
7130 IF EOF(1) THEN GOTO 7160
7140 INPUT #1, IPT,JPRPT(IPRIOR)
7150 GOTO 7120
7160 CLOSE #1
7170 LPRINT TAB(11);"PRIORITY DETAILS"
7180 LPRINT TAB(11);"Part Type Priority TAB(41);*** 1 INDICATES PRIORITY"
7190 LPRINT TAB(11);"TAB(41); 0 INDICATES NO PRIORITY"
7200 LPRINT TAB(11);"IPRIOR=IPRIOR+1:IPRIOR=0"
7210 LPRINT TAB(11);"FOR JH=1 TO IPRIOR-1"
7220 FOR JH=1 TO IPRIOR-1
7230 LPRINT TAB(11);"|TAB(13);JH;TAB(19);|;JPRPT(JH);TAB(29);|
7240 NEXT JH
7250 LPRINT TAB(11);"|;TAB(13);JH;TAB(19);|
7260 LOCATE 22,14:COLOR 30,0:PRINT "PRESS SPACE BAR TO CONTINUE"
7270 IF INKEY$ < > "" THEN GOTO 7270
7280 PRO%=INKEY$
7290 IF PRO% < > • THEN GOTO 7290
7300 CLS:COLOR 11,0:LOCATE 5,2:PRINT "FILE(S) THAT CONTAIN THE SYSTEM LAYOUT DETAILS : ";FILES "C:
7310 COLOR 10,0:PRINT:PRINT TAB(2);"ENTER NAME OF FILE THAT CONTAINS THE SYSTEM LAYOUT DETAILS : ";INPUT ", File4$=FILE4$+.LAY"
7320 IMM=0:FOR IFC=1 TO 9:DLOCM(IFC)=0;DULOM(IFC)=0;DSTM(IFC)=0;ITRACK(IFC)=0: NEXT IFC
7330 OPEN FILE4$ FOR INPUT AS #1
7340 IF EOF(1) THEN GOTO 7370
7350 INPUT #1, IMM,ITRACK(IMM),DLOCM(IMM),DULOM(IMM),DSTM(IMM)
7360 GOTO 7340
7370 CLOSE #1
7380 LPRINT CHR*(12)
7390 CLS:COLOR 11,0:LOCATE 13,20:PRINT "PRINTING SYSTEM LAYOUT DETAILS IN PROGRESS"
7400 LPRINT TAB(11);"SYSTEM LAYOUT DETAILS"
7410 LPRINT TAB(11);"Machine Lane Loading Station Unloading Station Central Tool Storage"
7420 LPRINT TAB(11);"|;TAB(16);IMF;TAB(21);|;TAB(24);ITRACK(IMF);TAB(29);|;TAB(32);DLOCM(IMF)
7430 LPRINT TAB(11);"|;TAB(44);DULOM(IMF);TAB(52);|;TAB(57);DSTM(IMF);TAB(67);|
7440 LPRINT TAB(11);"NEXT IMF"
7450 FOR IMM=1 TO IMM-1
7460 LPRINT TAB(11);"|;TAB(16);IMF;TAB(21);|;TAB(24);ITRACK(IMF);TAB(29);|;TAB(32);DLOCM(IMF)
7470 NEXT IMM
7480 LPRINT TAB(11);"|

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LOCATE 22,14:COLOR 30,0:PRINT "PRESS SPACE BAR TO CONTINUE"
7500 IF INKEY$ <> " " THEN GOTO 7500
7510 PRG$=INKEY$
7520 IF PRG$ <> " " THEN GOTO 7510
7530 CLS:COLOR 11,0:LOCATE 5,2:PRINT "FILE(S) THAT CONTAIN THE TIME AND SPEED DETAILS OF THE MHS:":FILES "C:*.TIM"
7540 COLOR 10,0:PRINT TAB(2);"ENTER THE NAME OF FILE THAT CONTAINS THE DETAILS OF MHS:":FILES$=FILES$+.TIM"
7550 OPEN FILES$ FOR INPUT AS #1
7560 INPUT #1,SPAGV,SPUAGV,SPCON,TTSLQ,TTULSO
7570 CLOSE #1
7580 CLS:COLOR 11,0:LOCATE 13,20:PRINT "PRINTING OF MHS DETAILS IN PROGRESS"
7590 FOR IP=1 TO 5:LPRINT:NEXT IP
7600 LPRINT TAB(11);"TIME AND SPEED DETAILS OF THE MATERIAL HANDLING SYSTEMS"
7610 LPRINT TAB(11);"---------------------------------------------------------------------------------
7620 LPRINT
7630 LPRINT TAB(11);"SPEED OF THE LOADING AGV" "SPAGV" [mts/min]
7640 LPRINT TAB(11);"SPEED OF THE UNLOADING AGV" "SPUAGV" [mts/min]
7650 LPRINT TAB(11);"SPEED OF THE TOOL CONVEYOR" "SPCON" [mts/min]
7660 LPRINT TAB(11);"TRAVEL TIME FOR THE LOADING CRANE" "TTSLQ" [mins]
7670 LPRINT TAB(11);"TRAVEL TIME FOR THE UNLOADING CRANE" "TTULSO" [mins]
7680 GOTO 350
SIMULATION MODEL FOR THE FLEXIBLE MANUFACTURING SYSTEM

DISCRETE EVENT SEGMENT-1

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************
METACOMMANDS
************
$STORAGE:2
$NOTRICT
$PAGESIZE:60
$LARGE
$LINE SIZE:132
$NOFLOATCALLS

THE MAIN PROGRAM

-----------COMMON BLOCK-------------

COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,
&NCLRHR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,
&TNOW,XX(100)
COMMON/UCOM1/ICOM,IDEOP,IND,IENT,IPAS,IPCQ,ISSFOL,ISTCO,ITOPA,
&JRU,JCMQ,MAG,NIQ,NMAC,NRANK,NTPT,IALTO(9),IDLEQ(9),IDQU(9)
COMMON/UCOM2/JPCRQ,PRINT,SPAGV,SPCON,SPUAV,STTSO,STULSO,STULM(9),
&STULM(9),DSTM(9),NF(30),PAR(25,220),MNF(30),ITRACK(9)
COMMON/UCOM3/ITCS(9),MACAQ(9),KTM(9,100)
COMMON/UCOM4/FINTIM,IRUN,ITRUN,IRUN,MPCOUNT,TENFB,JPPT(25)
COMMON/UCOM5/LCOUNT,NPARTY(25),DUEDT(25,30),JFOUT(25)
COMMON/UCOM6/NCRANE,NUCRANE,NULO,NUNCHP,NAGV,NUAVG,NPAM,NTRAC

DIMENSION IGD(3),IALM(9),ITool(10)
CHARACTER INIBUF*10,PARBUF(10)*50,ANS*1,PRINT*2,FULNAME*12,
&SELRULE*70,FILNAME*12

LOGICAL GEX

--- FILE 1 8 REFERS TO THE LINE PRINTER ---
OPEN(UNIT=8,FILE='PRN:')
DO 29 ISA=1,24
   WRITE(*,35)
29 CONTINUE
   WRITE(*,91)
91 FORMAT(/,10X,'PLEASE TURN ON THE PRINTER ')
   PAUSE

C --- SETTING UP THE PRINTER FOR THE COMPRESSED MODE ---
C
WRITE(8,14)CHAR(27),CHAR(15)
14 FORMAT(2A1)
C
WRITE(8,15)
15 FORMAT(30X,'**************************************************')
WRITE(8,16)
16 FORMAT(30X,'#')
WRITE(8,20)
20 FORMAT(30X,'SIMULATION OF AN FMS #')
WRITE(8,16)
WRITE(8,15)
WRITE(8,17)
17 FORMAT(/)
C
--- SELECTION OF THE REQUIRED RULE ---
C
25 CONTINUE
DO 30 ISA=1,24
   WRITE(*,35)
30 CONTINUE
   WRITE(*,40)
40 FORMAT(10X,'SCHEDULING RULES THAT ARE AVAILABLE : ')
   WRITE(*,45)
45 FORMAT(//,15X,'1. Random selection rule [ RANDOM ]')
   WRITE(*,50)
50 FORMAT(//,15X,'2. Fewest operations remaining [ FOPR ]')
   WRITE(*,55)
55 FORMAT(//,15X,'3. Most operations remaining [ MOPR ]')
   WRITE(*,60)
60 FORMAT(//,15X,'4. Shortest processing time [ SPT ]')
   WRITE(*,65)
65 FORMAT(//,15X,'5. Longest processing time [ LPT ]')
   WRITE(*,70)
70 FORMAT(///,10X,'ENTER THE SCHEDULING RULE YOU NEED ; ,\nREAD(*',BN,I2)')JRU
IF(JRU.GT.5.DR.JRU.LT.0) THEN
   WRITE(*,80)CHAR(7)
80 FORMAT(A1,25X,'WRONG CHOICE - PLEASE ENTER AGAIN ')
GO TO 25
ELSE
PRINT='O F ' WRITE(*,85)
95 FORMAT(1,10X,'ENTER THE TOTAL NUMBER OF RUNS : ',
READ(*,'(BN,15)'),ITRUN
89 WRITE(*,86)
96 FORMAT(1,10X,'DO YOU WANT TO TRACE THE SIMULATION [ Y OR N ] '
WRITE(*,87)
87 FORMAT('?',
READ(*,'(AI)'),ANS
IF(ANS.EQ.'Y'.OR.ANS.EQ.'n') THEN
PRINT='ON'
ELSEIF(ANS.EQ.'N'.OR.ANS.EQ.'n') THEN
PRINT='OF'
ELSE
WRITE(*,88)CHAR(7)
88 FORMAT(1,25X,'WRONG CHOICE - PLEASE TRY AGAIN')
GO TO 89
ENDIF
C --- WRITING TITLE OF RULE SELECTED ---
C
IF(JRU.EQ.1) THEN
SELRULE='Random selection rule [ RANDOM ]'
ELSEIF(JRU.EQ.2) THEN
SELRULE='Fewest operations remaining [ FOPR ]'
ELSEIF(JRU.EQ.3) THEN
SELRULE='Most operations remaining [ MOPR ]'
ELSEIF(JRU.EQ.4) THEN
SELRULE='Shortest processing time [ SPT ]'
ELSEIF(JRU.EQ.5) THEN
SELRULE='Longest processing time [ LPT ]'
ELSE
ENDIF
WRITE(*,90)SELRULE
90 FORMAT(1,10X,'Scheduling rule used : ',A70)
C --- INITIALISATION BLOCK ---
C
IPRI0R=0
IRUN=0
IREC=0
KTF=0
NMREC=0
IDE0P=10
DO 105 ISC=1,25
    DO 110 ISD=1,30
        DUEDAT(ISC,ISD)=0.0
        REPRODUCED WITH PERMISSION OF THE COPYRIGHT OWNER. FURTHER REPRODUCTION PROHIBITED WITHOUT PERMISSION.
CONTINUE
CONTINUE

C

C ---- ACCESSING DATA FROM THE DATA FILES ----

C

DO 115 JX=1,24
WRITE(*,120)
120 FORMAT(/)
115 CONTINUE

C

C ---- OPENING FILE 1 ----

C

140 WRITE(*,125)
125 FORMAT(/,1X,'ENTER NAME OF FILE THAT STORES THE PART DATA ; ',
READ(*,A)')FULNAME
INQUIRE(FILE=FULNAME,EXIST=QEX)
IF(QEX.EQV.!.FALSE.)) THEN
WRITE(*,130)CHAR(7),CHAR(7),FULNAME
130 FORMAT(2A1,'FILE ',A12,' DOES NOT EXIST IN HARD DISK - ',
WRITE(*,135)
135 FORMAT()TRY AGAIN')
GO TO 140
ELSE
OPEN(UNIT=1,FILE=FULNAME,STATUS='OLD',ACCESS='SEQUENTIAL',
&FORM='FORMATTED')
ENDIF

C

C ---- FILE 1 HAS BEEN OPEN ----

C

DO 145 IRA=1,25
DO 150 IRB=1,220
PARR(IRA,IRB)=0.0
150 CONTINUE
145 CONTINUE
155 IREC=IREC+1
READ(1,160,END=165)INIBUF,(PARBUF(N),N=1,10)
160 FORMAT(A10,10(A58))
READ(INIBUF,170)IGD(J),J=1,3
170 FORMAT(I2,1X,I3,1X,I2,1X)
PARR(IREC,1)=IGD(1)
PARR(IREC,2)=IGD(2)
PARR(IREC,3)=IGD(3)
DO 175 K=1,10
J1=4+(K-1)*21
READ(PARBUF(K),180)PRT,IFT,(IALM(J),J=1,9),(ITool(J),J=1,1
&0)
180 FORMAT(46.2,1X,I2,1X,9(I1,1X),10(I2,1X))
PARR(IREC,J1)=PRT
PARR(IREC,J1+1)=IFT
L1=1
DO 185 LJ=J1+2, J1+10
   PARR(IREC,LJ)=IALM(L1)
   LI=LI+1
185 CONTINUE
L2=1
DO 195 LT=J1+11, J1+20
   PARR(IREC,LT)=I TOOL(L2)
   L2=L2+1
195 CONTINUE
175 CONTINUE
GO TO 155
165 NTPT=IREC-1
CLOSE(1, STATUS='KEEP')
C
C --- FILE 1 IS CLOSED -- ALL PART DETAILS ARE STORED IN THE ARRAY -----
C
C --- OPENING FILE 2 ----
C
215 WRITE(*,200)
200 FORMAT(/,IX,'ENTER NAME OF FILE THAT STORES PRIORITY DATA : ','
READ(*,'(A)')FULNAME
INQUIRE(FILE=FULNAME,EXIST=QEX)
IF(QEX.EQV..FALSE.)) THEN
   WRITE(*,205)CHAR(7),CHAR(7),FULNAME
205 FORMAT(2A1,'FILE ',A12,' DOES NOT EXIST ON HARD DISK - ','
   WRITE(*,210)
210 FORMAT('TRY AGAIN')
   GO TO 215
ELSE
   OPEN(UNIT=2,FILE=FULNAME,STATUS='OLD',ACCESS='SEQUENTIAL',
   &FORM='FORMATTED')
ENDIF
DO 220 ISE=1,25
   JPRPT(ISE)=0
220 CONTINUE
235 IPRIOR=IPRIOR+1
   READ(2,225,END=230)IPF, JPRPT(IPPRIOR)
225 FORMAT(10X,I3,5X,I2)
   GO TO 235
230 CLOSE(2, STATUS='KEEP')
C
C --- FILE 2 IS CLOSED -- PRIORITY DETAILS FOR ALL PART TYPES ACCESSED ---
C
C --- OPENING FILE 3 ---
C
295 WRITE(*,280)
280 FORMAT(/,IX,'ENTER NAME OF FILE THAT STORES LAYOUT DATA : ','
READ(*,'(A)')FULNAME
INQUIRE(FILE=FULNAME,EXIST=QEX)
IF(QEX.EQV..FALSE.)) THEN
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WRITE(*,285)CHAR(7),CHAR(7),FULNAME
285 FORMAT(2A1,'FILE ',A12,' DOES NOT EXIST ON HARD DISK - ',\)
WRITE(*,290)
290 FORMAT('TRY AGAIN')
GO TO 295
ELSE
OPEN(UNIT=3,FILE=FULNAME,STATUS='OLD',ACCESS='SEQUENTIAL',\)
&FORM='FORMATTED')
ENDIF
DO 300 IZZ=1,9
ITRACK(IZZ)=0
DL0M(IZZ)=0.0
DUL0M(IZZ)=0.0
DSTM(IZZ)=0.0
300 CONTINUE
315 NMREC=NMREC+1
READ(3,305,END=310)NUM,ITRACK(NMREC),DL0M(NMREC),DUL0M(NMREC),DSTM(NMREC)
305 FORMAT(5X,I3,5X,I2,10X,F7.2,5X,F7.2,5X,F7.2)
GO TO 315
310 NMAC=NMREC-1
CLOSE(3,STATUS='KEEP')
C
C --- FILE 3 CLOSED -- ALL SYSTEM LAYOUT DETAILS HAVE BEEN ACCESSED ---
C
C --- OPENING FILE 4 ---
C
335 WRITE(*,320)
320 FORMAT(/,IX,'ENTER NAME OF FILE THAT STORES MHS TIME DATA : ',\)
READ(*,'(A')FULNAME
INQUIRE(FILE=FULNAME,EXIST=QEX)
IF(QEX.EQV.(.FALSE.)) THEN
WRITE(*,325)CHAR(7),CHAR(7),FULNAME
325 FORMAT(2A1,'FILE ',A12,' DOES NOT EXIST ON HARD DISK - '),\)
WRITE(*,330)
330 FORMAT('TRY AGAIN')
GO TO 335
ELSE
OPEN(UNIT=4,FILE=FULNAME,STATUS='OLD',ACCESS='SEQUENTIAL',\)
&FORM='FORMATTED')
ENDIF
READ(4,340)SPAGV,SPUAGV,SPCON,TTSLO,TTULSO
340 FORMAT(10X,6(F7.3,SX),15X,2(F7.3,SX))
CLOSE(4,STATUS='KEEP')
C
365 WRITE(*,345)
345 FORMAT(/,IX,'DO YOU WANT A PRINT OUT OF THE INPUT DETAILS ',\)
WRITE(*,350)
350 FORMAT(' [ 1-Yes, 2-No ] ? ',\)
READ(*,'(BN,12)')IAN
IF (IAN.EQ.1) THEN
   GO TO 355
ELSEIF (IAN.EQ.2) THEN
   GO TO 615
ELSE
   WRITE(*,360) CHAR(7)
360 FORMAT(20X,'WRONG CHOICE - PLEASE TRY AGAIN ')
   GO TO 365
ENDIF

C SEGMENT THAT PRINTS OUT THE INPUT DETAILS OF THE SIMULATION MODEL

C 355 CONTINUE
   WRITE(*,95)
   95 FORMAT(/,10X,'Details of all the part types to be ',/
   WRITE(*,100)
   100 FORMAT('manufactured in the planning period ',/
   WRITE(*,356)
   356 FORMAT(T11,'PART TYPE DETAILS ',/)
   WRITE(*,375)
   375 FORMAT(10X,'--------------------------------------------------------------------------------------------------',/
   WRITE(*,380)
   380 FORMAT('--------------------------------------------------------------------------------------------------')
   WRITE(*,385)
   385 FORMAT(10X,'| Part | Batch | Opn | Proc. | FT | Mac',/
   WRITE(*,390)
   390 FORMAT('hine(s) | Tools required |')
   WRITE(*,391)
   391 FORMAT(10X,'| Type | Size | No. | Time | | ',/
   WRITE(*,392)
   392 FORMAT('|')
   WRITE(*,393)
   393 FORMAT(10X,'--------------------------------------------------------------------------------------------------',/
   WRITE(*,394)
   394 FORMAT('--------------------------------------------------------------------------------------------------')
   DO 370 LN=1,NTPT
   LABS=PARR(LN,2)
   LNOP=PARR(LN,3)
   J11=4
   WRITE(*,395) LN, LABS
   395 FORMAT(T11,'|',T13,I2,T18,'|',T20,I3,\)
   DD 400 MN2=1,LNOP
   IFTY=PARR(LN,J11+1)
   WRITE(*,405)MN2,PARR(LN,J11),IFTY
   405 FORMAT(T26,'|',T28,I2,T32,'|',2X,F6.2,T44,'|',1X,I2,\)
   WRITE(*,407)
   407 FORMAT(T49,'| ',\)
   ICDE=0
   DD 410 JA=J11+2,J11+10
   IALMAC=PARR(LN,JA)
ICDE=ICDE+1
IF(INRAC.EQ.0) GO TO 420
IF(INRAC.EQ.1) GO TO 416
WRITE(8,415)INRAC
415 FORMAT(II,\)
GO TO 410
416 WRITE(8,417)INRAC
417 FORMAT('or',II,\)
410 CONTINUE
420 WRITE(8,425)
425 FORMAT(II,\)
ICTA=0
DO 430 JAB=J11+11,J11+20
INRAC=PARR(LN,JAB)
ICTA=ICTA+1
IF(INRAC.EQ.0) GO TO 440
IF(INRAC.EQ.1) GO TO 436
WRITE(8,435)INRAC
435 FORMAT(12,\)
GO TO 430
436 WRITE(8,437)INRAC
437 FORMAT(',12,\)
430 CONTINUE
440 WRITE(8,445)
445 FORMAT(II2,',',\)
J11=J11+21
IF(LN2.EQ.LN0P) GO TO 400
WRITE(8,450)
450 FORMAT('I  I  ',\)
400 CONTINUE
IF(LN.EQ.NTPT) GO TO 454
WRITE(8,451)
WRITE(8,461)
461 FORMAT(T11,'---------------------'
DO 475 IPRI=1,NTPT
     WRITE(8,4B0)IPRI,JPRPT(IPRI)
480 FORMAT(T11,''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
WRITE(8,605)
605 FORMAT(1X,'Travel time for the unloading crane from the unloa',\)
WRITE(8,610)TULSO
610 FORMAT('ing station to the Central Parts Storage =',F7.3
& ','[minsl'l
WRITE(8,611)
611 FORMAT(//)
C
C --- RESOURCE QUANTITIES INPUT FROM TERMINAL ---
C
615 CONTINUE
   DO 616 IXQ=1,24
      WRITE(*,617)
617 FORMAT(//)
   616 CONTINUE
WRITE(*,618)
618 FORMAT(1X,'DETAILS OF THE RESOURCES USED TO BE ENTERED')
WRITE(*,619)
619 FORMAT(1X,'-----------------------------------------------')
WRITE(*,620)
620 FORMAT(1X,'ENTER THE NUMBER OF LOADING CRANES AVAILABLE ---- ',\)
READ(*,'(BN,I3)')NCRANE
WRITE(*,625)
625 FORMAT(1X,'ENTER THE NUMBER OF UNLOADING CRANE AVAILABLE ---- ',\)
READ(*,'(BN,I3)')NUCRANE
WRITE(*,630)
630 FORMAT(1X,'ENTER THE NUMBER OF LOADERS AVAILABLE---------- ',\)
READ(*,'(BN,I3)')NUL0
WRITE(*,635)
635 FORMAT(1X,'ENTER THE NUMBER OF UNLOADERS AVAILABLE-------- ',\)
READ(*,'(BN,I3)')NUNL0
WRITE(*,640)
640 FORMAT(1X,'ENTER THE NUMBER OF LOADING AGVs AVAILABLE---- ',\)
READ(*,'(BN,I3)')NAGV
WRITE(*,645)
645 FORMAT(1X,'ENTER THE NUMBER OF UNLOADING AGVs AVAILABLE---- ',\)
READ(*,'(BN,I3)')NUAGV
WRITE(*,650)
650 FORMAT(1X,'ENTER THE NUMBER OF PALLETS AVAILABLE---------- ',\)
READ(*,'(BN,I3)')NPAL
WRITE(*,652)
652 FORMAT(1X,'ENTER THE NUMBER OF LANES IN THE SYSTEM------- ',\)
READ(*,'(BN,I3)')NTRAC
C
C --- FIXTURE TYPE QUANTITIES INPUT FROM TERMINAL ---
C
   DO 661 IUD=1,24
      WRITE(*,617)
661 CONTINUE
   DO 662 LNF=1,30
      WRITE(*,617)
662 CONTINUE
NF(LNF)=0
MNF(LNF)=0
662 CONTINUE
WRITE(*,663)
663 FORMAT(I,ENTER THE NUMBER OF FIXTURE TYPES USED -- ',\(,\)
READ(*,BN,I3)JFTY
DO 664 KTF=1,JFTY
WRITE(*,666)KTF
666 FORMAT(/,QUANTITY OF FIXTURE TYPE\(,13,' AVAILABLE --- ',\(,\)
READ(*,BN,I3)NUFT
NF(KTF)=NUFT
MNF(KTF)=NUFT
664 CONTINUE
C
NCRDR=5
NPRNT=0
NTAPE=7
DO 653 IAS=1,24
WRITE(*,654)
654 FORMAT(/)
653 CONTINUE
WRITE(*,656)SELRULE
656 FORMAT(A12,'Scheduling rule requested is ',A55)
C
C — DECIDING THE RIGHT TRANSLATED FILE —
C
IF(JRU.EQ.1) THEN
FILNAM='RAND.TRA'
ELSEIF(JRU.EQ.2) THEN
FILNAM='FOPR.TRA'
ELSEIF(JRU.EQ.3) THEN
FILNAM='MOPR.TRA'
ELSEIF(JRU.EQ.4) THEN
FILNAM='SPT.TRA'
ELSEIF(JRU.EQ.5) THEN
FILNAM='LPT.TRA'
ELSE
ENDIF
WRITE(*,657)
657 FORMAT(/,FILE NAME OF THE TRANSLATED FILE THAT YOU HAVE \',\)
WRITE(*,658)FILNAM
658 FORMAT('TO USE \',A12)
PAUSE
CALL SLAM
END
C
C — ALL THE RELEVANT DATA ACCESSED FROM THE DATA FILES —
C
C
C ********************
C INITIALIZATION ROUTINE

SUBROUTINE INTLC

C **************************

COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,
&NCLR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TEND,
&TNOW,XX(100)

COMMON/UCOM1/ICOM,IDEOP,IDG,IEND,IPA5,IPCO,ISRFOL,ISTCO,ITOPA, 
&JRU,JCMQ,MAG,NIQ,NMAC,NAHAE,NTPT,IVALO(9),IDEQ(9),IDQU(9)

COMMON/UCOM2/JPCRA,PRINT,SPAGV,SPCON,SPUAGV,TTSTO,TTSTO,DLQIM(9),
&DLQIM(9),DSTM(9),NF(30),PARR(25,220),MN(30),ITRACK(9)

COMMON/UCOM3/ITCS(9),MACAQ(9),KTM(9,100)

COMMON/UCOM4/FINTIM,IRUN,ITRUN,MPCOUNT,TPFB,JPRPT(25)

COMMON/UCOM5/MPCOUNT,MPCOUNT,MPVAT(25),PARR(25,30),JFOUT(25)

COMMON/UCOM7/NCRANE,NCRANE,NUSL,NUSL,NAGV,NAGV,NPAL,NTRAC

COMMON/UCOM7/PAR4,PAR4,PAR4,PAR4,PAR4,PAR4,PAR4,PAR4,PAR4

CHARACTER PRINT*2

C — ALTERING THE MACHINES —

DO 665 IM=1,NMAC
   CALL ALTER(IM,1)
665 CONTINUE

C — ALTERING THE COMMON RESOURCES —

CALL ALTER(10,NCRANE)
CALL ALTER(II,NCRANE)
CALL ALTER(12,NULQ)
CALL ALTER(13,NUSL)
CALL ALTER(14,NAGV)
CALL ALTER(15,NAGV)
CALL ALTER(16,NPAL)

C — ALTERING THE NUMBER OF FIXTURE TYPES —

DO 670 IFX=1,30
   NUFF=MNF(IFX)
   CALL ALTER(IFX+16,NUFF)
670 CONTINUE

C — ALTERING THE NUMBER OF TRACKS —

DO 675 ITR=1,NTRAC
   CALL ALTER(ITR+46,1)
   CALL ALTER(ITR+51,1)
675 CONTINUE

IRUN=IRUN+1
IF(IRUN.GT.1) GO TO 715

C --- PRINTING OUT THE RESOURCE DETAILS ---

C

WRITE(B,565)CHAR(27),CHAR(12)
565 FORMAT(2A1)
WRITE(B,679)
679 FORMAT(/,10X,'RESOURCE DETAILS FOR THE FMS ')
WRITE(B,680)NNRSC
680 FORMAT(/,10X,'Number of loading cranes = ',I11)
WRITE(B,685)NNRSC
685 FORMAT(10X,'Number of unloading cranes = ',I11)
WRITE(B,690)NNRSC
690 FORMAT(10X,'Number of human loaders = ',I11)
WRITE(B,695)NNRSC
695 FORMAT(10X,'Number of human unloaders = ',I11)
WRITE(B,700)NNRSC
700 FORMAT(10X,'Number of loading AGVs = ',I11)
WRITE(B,705)NNRSC
705 FORMAT(10X,'Number of unloading AGVs = ',I11)
WRITE(B,710)NNRSC
710 FORMAT(10X,'Number of pallets used = ',I12)
WRITE(B,490)
490 FORMAT(T11,'FIXTURE TYPE DETAILS',/)
WRITE(B,495)
495 FORMAT(T11,'- - - - - - - - - - - - -')
WRITE(B,500)
500 FORMAT(T11,' Fixture | Quantity |')
WRITE(B,505)
505 FORMAT(T11,' Type | |')
WRITE(B,510)
510 FORMAT(T11,'- - - - - - - - - - - - -')
DO 515 IFX=1,30
   IF(MNF(IFX).EQ.0) GO TO 525
   WRITE(B,520)IFX,MNF(IFX)
520 FORMAT(T11,' [3X,12,4X,’”’,4X,12,4X,’”’]
515 CONTINUE
525 WRITE(B,526)
526 FORMAT(T11,'- - - - - - - - - - - - -')
WRITE(B,530)
530 FORMAT(///)

C --- FILING ALL THE PARTS IN THE CENTRAL STORAGE ---

C

715 CONTINUE
IPC0=0
JCT1=21
JCT2=17
DO 720 JNT=1,NTPT
   JBS=PARR(JNT,2)
DO 725 JK=1,JBS
   DO 730 JA=1,100
      ATRIB(JA)=0.0
   CONTINUE
   IPC0=IPC0+1
   ATRIB(1)=JPRPT(JNT)
   ATRIB(2)=IPC0
   ATRIB(3)=JNT
   ATRIB(4)=PARR(JNT,3)
   ATRIB(5)=1.
   JAN=ATRIB(5)
   JCT3=JAN*JCT1-JCT2
   ATRIB(6)=PARR(JNT,JCT3)
   ATRIB(7)=PARR(JNT,JCT3+1)
   DO 735 JAT=22,40
      ATRIB(JAT)=PARR(JNT,JCT3+2)
      JCT3=JCT3+1
   CONTINUE
   IF(JRU.EQ.1) THEN
      PUTRAND=DRAND(1)
      ATRIB(9)=PUTRAND
   ELSE
      ENDIF
   CALL FILEH(20,ATRIB)
   JCT3=0
725 CONTINUE
720 CONTINUE
   ITOPA=NNB(20)
   IF(IRUN.GT.1) GO TO 740
   WRITE(8,745)
745 FORMAT(/,10X,'Total number of parts in the Central Parts ')
   WRITE(8,750)ITOPA
750 FORMAT('Storage at the start of the simulation = ',I4,/) 
   WRITE(8,751)
751 FORMAT(/)
C
--- INDICATION ON SCREEN ---
C
740 CONTINUE
   DO 742 ISF=1,24
      WRITE(*,744)
744 FORMAT(/)
   CONTINUE
742 CONTINUE
   WRITE(*,755)5X,'SIMULATION IN PROGRESS'
755 FORMAT(5X,'SIMULATION IN PROGRESS'
   WRITE(*,760)
760 FORMAT(5X,'**************************************************************/'
   WRITE(*,770)IRUN
770 FORMAT(6X,'RUN NUMBER ',I3,/) 
   IF(PRINT.EQ.'O F') GO TO 771

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WRITE(8,773)CHAR(27),CHAR(12)
773 FORMAT(2AI)
WRITE(8,772)IRUN
772 FORMAT(/,1X,'TRACE OF RUN ','12,' OF THE SIMULATION',/)

C
C --- INITIALIZATION OF OTHER VARIABLES IN THE PROGRAM ---
C
771 CONTINUE
50 DO 775 K K = 1,100
XX(KK)=0.0
775 CONTINUE
50 DO 780 IH=1,9
ITCS(IH)=0
780 CONTINUE
50 DO 785 K L M =1,100
KTM(IH,KLM)=0
785 CONTINUE
50 DO 790 ISG=1,25
JFOUT(ISG)=0
NPARTY(ISG)=0
790 CONTINUE
50 ISTCO=0
ISRFOL=0
JPCRA=0
MPCOUNT=0
IENT=0
IPAS=0
JCMAQ=0
LCOUNT=0
MAG=0
FINITIM=99999.00
RETURN
END
C
C *****************************************************
C ROUTINE FOR SELECTING THE APPROPRIATE EVENT
C *****************************************************
SUBROUTINE EVENT(I)
C - - - - - - - - - - - - - - -— COMMON BLOCK—- - -— — — —-- - - - --- - -
COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,
&NCLNR,NCRDR,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,
&TNOW,XX(100)
COMMON/UCOM1/ICOM,IDEOP,IDQ,IENT,IPAS,IPCO,ISRFOL,ISTCO,ITOPA,
&JRU,JCMAG,MAQ,NIQ,NMAC,NRANK,NTPT,ITLAQ(9),IDLEQ(9),IDQU(9)
COMMON/UCOM2/JPCRA,PRINT,SPAGV,SPCON,SPUAGV,TTSL0,TTULSO,
&DL0M(9),DULOM(9),DM(9),DSTM(9),NF(30),PARR(25,220),MNF(30),ITAK(9)
COMMON/UCOM3/ITCS(9),MACAG(9),KTM(9,100)
COMMON/UCOM4/FINITIM,IRUN,ITRUN,MARO,MPCOUNT,TENFB,JPRPT(25)
COMMON/UCOM5/LCOUNT,NPARTY(25),DUEDAT(25,30),JFOUT(25)
COMMON/UCOM7/ICRANE, IUCRANE, IULO, IUNLO, IAGV, IUAGV, IPAL
C

C -----------------------------------------------
C CHARACTER PRINT*2
C
C ----------- ROUTINES THAT ARE EXTERNAL TO THIS SEGMENT ---
C
EXTERNAL PARTIN, RELAGVL, TOOLCAPT, FREEBUF, RELFIXT, REENTER,
&REATRIB, PLOTFACT
GO TO (1,2,3,4,5,6,7,8), I
1 CALL PARTIN
RETURN
2 CALL RELAGVL
RETURN
3 CALL TOOLCAPT
RETURN
4 CALL FREEBUF
RETURN
5 CALL RELFIXT
RETURN
6 CALL REENTER
RETURN
7 CALLreated
RETURN
8 CALL PLOTFACT
RETURN
END
C

C *********************************************** ***********
C ROUTINE FOR THE ALLOCATION AT THE VARIOUS NODES -- ALLOCATE(I)
C *********************************************** ***********

SUBROUTINE ALLOC(ICODE, IFLAG)

C -----------------------------------------------
COMMON/UCOM1/ATRIB(100), DD(100), DDL(100), DTNOW, II, MFA, MSTOP,
&NCLNR, NCAR, NPRT, NNRUN, MNSET, NTAPE, SS(100), SSL(100), TNEXT,
&TNOW, XX(100)
COMMON/UCOM2/IDCRA, PRINT, SPAGV, SPCON, SUAGV, TTSLO, TTULSO, DALM(9),
&DDLM(9), DSTM(9), NF(30), PARR(25, 220), MNF(30), ITRACK(9)
COMMON/UCOM3/ITCS(9), MACAQ(9), KTM(9, 100)
COMMON/UCOM4/FINTIM, IRUN, ITRUN, MRCNT, MFCOUNT, TENFB, JPRPT(25)
COMMON/UCOM5/LCOUNT, NPARTY(25), DUEDAT(25, 30), JFQOUT(25)
COMMON/UCOM7/ICRANE, IUCRANE, IULO, IUNLO, IAGV, IUAGV, IPAL
C -----------------------------------------------

CHARACTER PRINT*2
IFLAG=0
GO TO (805, 810, 815), ICODE
C
C ----------- ALLOCATION OF LOADING CRANE, LOADING AGV, PALLET, LOADER &
C FIXTURE TYPE ----
C
805 IFIX=ATRIB(7)
      CALL SEIZE(10,1)
      CALL SEIZE(12,1)
      CALL SEIZE(14,1)
      CALL SEIZE(16,1)
      CALL SEIZE(IFIX+16,1)
      IF(PRINT.EQ.'OF') GO TO 806
      IPZ1=ATRIB(2)
      WRITE(8,807)TNOW,IPZ1
507 FORMT(10X,'TIME = ',F10.4,' PART # ',13,' SEIZES THE LOAD'),
      WRITE(8,808)
508 FORMT('NG CRANE, LOADING AGV, LOADER, PALLET AND FIXTURE')
506 IFLAG=-1
      RETURN
   ELSE
      RETURN
   ENDIF
C
C --- ALLOCATION OF THE EXACT LOADING TRACK ---
C
810 KTRA=ATRIB(10)
   IF(NRUSE(KTRA+46).EQ.0) THEN
      CALL SEIZE(KTRA+46,1)
      IFLAG=-1
      RETURN
   ELSE
      RETURN
   ENDIF
C
C --- ALLOCATION OF UNLOADING AGV, UNLOADER AND UNLOADING CRANE ---
C
815 LTRA=ATRIB(10)
   IF(NNRSC(11).GE.1 .AND. NNRSC(13).GE.1 .AND. NNRSC(15).GE.1 .AND. NRUSE(LTRA+51).EQ.0) THEN
      CALL SEIZE(11,1)
      CALL SEIZE(13,1)
      CALL SEIZE(15,1)
      CALL SEIZE(LTRA+51,1)
      IF(PRINT.EQ.'OF') GO TO 816
      IPZ2=ATRIB(2)
      WRITE(8,817)TNOW,IPZ2
517 FORMT(10X,'TIME = ',F10.4,' PART # ',13,' SEIZES THE UNLOAD'),
      WRITE(8,818)
518 FORMT('NG CRANE, UNLOADER, AND UNLOADING CRANE')
516 IFLAG=-1
      RETURN

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ELSE
    RETURN
ENDIF
END

C USER FUNCTION ROUTINES

FUNCTION USERF(I)

C - - - - - - - - - - - - - - - - -COMMON BLOCK- - - - - - - - - - - - - - - - - - - - - - -
COMMON/SCOM1/ATRIB(100), DD(100), DDL(100), DTNOW, II, MFA, MSTOP,
&NLNR, NCRDR, NPRT, NNRUN, NNSET, NTAPE, SS(100), SSL(100), TNEXT,
&TNOW, XX(100)
COMMON/UCOM1/IDEX, IOQ, IEN, IPAS, IPCO, IRSFD, ISTCO, ITOPA,
&JRU, JCMAG, MG, NIQ, NMAC, NRANK, NOTP, IALTQ(I), IDLD(100), IDQU(100)
COMMON/UCOM2/JPCRA, PRINT, SPAGV, SPCON, SPUAQV, TTLOM, TTULSO, TTSLO, DULOM(10),
&DULOM(10), DSTM(9), NF(30), PARR(25, 220), MNF(30), ITRACK(9)
COMMON/UCOM3/ITCS(9), MACAQ(9), KTM(9, 100)
COMMON/UCOM4/FINTIM, IRUN, ITRUN, MARO, HPCOUNT, TENFB, JPRT(25)
COMMON/UCOM5/ICOUNT, NPARTY(25), DEDAT(25, 30), JFOUT(25)
COMMON/UCOM7/ICRANE, ICRANE, IULC, IULA, IAGV, IUAQ, ALAP
COMMON/UCOM7/ICRANE, ICRANE, IULC, IULA, IAGV, IUAQ, ALAP

CHARACTER PRINT*2

GO TO (855, 860, 865, 870, 875, 880, 885), I

C — TRANSPORT TIME FROM CENTRAL PARTS STORAGE TO LOADING STATION —

C

855 IF(JPCRA.EQ.0) THEN
    USERF=TTSLO
    JPCRA=1
ELSEIF(JPCRA.EQ.1) THEN
    USERF=2*TTSLO
ELSE
    ENDIF
    IF(PRINT.EQ.'OF') RETURN
    IPZ3=ATRIB(2)
    NRITE(8, 857) TNOW, IPZ3
     857 FORMAT(10X, 'TIME = ', F10.4, '  PART # ', 'I3,' TRANSPORTED FROM TH', 'I')
     WRITE(8, 858) USERF
     858 FORMAT('E C P S TO THE LOADING STATION - TRAVEL TIME = ', F6.3)
    RETURN

C — TRANSPORT TIME FROM LOADING STATION TO THE EXACT MACHINE —

C

860 MARO=ATRIB(8)
    DTLOM=DULOM(MARO)/SPAGV
    USERF=DTLOM
    IF(PRINT.EQ.'OF') RETURN
    IPZ4=ATRIB(2)
    MTRAC=ATRIB(10)

RETURN
WRITE(8,861)TNOW,IPZ4
861 FORMAT(10X,'TIME = ',F10.4,' PART # ',I3,' TRANSPORTED FROM LO',\)
WRITE(8,862)MARO,USERF
862 FORMAT('ADING STATION TO MACHINE ',I1,' - TRAVEL TIME = ',F6.3)
WRITE(8,863)IPZ4
863 FORMAT(20X,'LOADING AGV CARRYING PART # ',I3,' MOVING ON ',\)
WRITE(8,864)MTRAC
864 FORMAT('LOADING TRACK ',I2)
RETURN

C --- TRAVEL TIME FOR EMPTY CART FROM MACHINE TO THE LOADING STATION ---

C 865 MACHO=ATRIB(8)
TTMLO=DLOM(MACHO)/SPAGV
USERF=TTMLO
IF(PRINT.EQ.'OF') RETURN
IPZ5=ATRIB(2)
MMTRAC=ATRIB(10)
WRITE(8,866)TNOW,IPZ5
866 FORMAT(10X,'TIME = ',F10.3,' PART # ',I3,' RELEASES CART AT MA',\)
WRITE(8,867)MACH0,USERF
867 FORMAT('CHINE ',I1,' - AGV TRAVEL TIME TO C P S = ',F6.3)
WRITE(8,868)MMTRAC
868 FORMAT(20X,'EMPTY LOADING AGV MOVING ON LOADING TRACK ',I2)
RETURN

C --- TRAVEL TIME FROM TOOL STORAGE TO MACHINE ---

C 870 MACGO=ATRIB(8)
IF(ITCS(MACGO).EQ.0) THEN
USERF=0.0
ELSE
USERF=DSTM(MACGO)/SPCON
ENDIF
ITCS(MACGO)=0
IF(PRINT.EQ.'OF') RETURN
IPZ6=ATRIB(2)
WRITE(8,871)TNOW,IPZ6
871 FORMAT(10X,'TIME = ',F10.4,' PART # ',I3,' WAITS FOR TOOLS FR',\)
WRITE(8,872)MACGO,USERF
872 FORMAT('OM THE TOOL CRIB AT MACHINE ',I1,' - WAITING TIME = ',\&F6.3)
RETURN

C --- TRANSPORT TIME FROM THE MACHINE TO THE UNLOADING STATION ---

C 875 MAFO=ATRIB(8)
TTMAUL=DULOM(MAFO)/SPUAGV
USERF=2*TTMAUL
IF(PRINT.EQ.'OF') RETURN
IPZ7=ATRIB(2)
MNTRAC=ATRIB(10)
WRITE(8,B76)TNOW,IPZ7
876 FORMAT(10X,'TIME = ',F10.4,' PART # ',I3,' TRANSPORTED FROM MA',\)
   WRITE(8,B77)MAF0,USERF
877 FORMAT('CHINE ',I1,' TO UNLOADING STATION - TRAVEL TIME = ',F6.3)
   WRITE(8,B78)IPZ7
878 FORMAT(20X,'UNLOADING AGV CARRYING PART # ',I3,' MOVING ON ',\)
   WRITE(8,B79)MNTRAC
879 FORMAT('UNLOADING TRACK ',I2)
   RETURN
C --- TRAVEL TIME FOR UNLOADING CRANE FROM PARTS STORAGE TO UNLOADING
C STATION -------
C
880 USERF=TTULSO
   IF(PRINT.EQ.'OF') RETURN
   IPZ8=ATRIB(2)
   WRITE(8,B81)TNOW,IPZ8
881 FORMAT(10X,'TIME = ',F10.4,' PART # ',I3,' WAITS FOR THE UNLOAD',\)
   WRITE(8,B82)USERF
882 FORMAT('ING CRANE AT THE UNLOADING STATION - WAITING TIME = ',\)
   &F6.3)
   RETURN
C --- TRAVEL TIME FOR UNLOADING CRANE TO THE CENTRAL PARTS STORAGE ---
C
885 USERF=TTULSO
   IF(PRINT.EQ.'OF')RETURN
   IPZ9=ATRIB(2)
   WRITE(8,B86)TNOW,IPZ9
886 FORMAT(10X,'TIME = ',F10.4,' PART # ',I3,' TRANSPORTED FROM TH',\)
   WRITE(8,B87)USERF
887 FORMAT('E UNLOADING STATION TO THE CPS - TRAVEL TIME = ',F6.3)
   RETURN

END

----------------------------------------

SIMULATION OF FLEXIBLE MANUFACTURING SYSTEM

DISCRETE EVENT SEGMENT - 2

----------------------------------------

******
META COMMANDS
******
SUBROUTINE PARTIN

- - - - - - - - - - - - - - - - -COMMON BLOCK- - - - - - - - - - - - - - - - - - - - - - -
COMMON/SCOM1/ATRIB(100),DD(100),DTNOW,II,MFA,MSTOP,
&NCLNR,NCOR,NPRINT,NRRUN,NSET,NTAPE,SS(100),SSL(100),TNEXT,
&TNOW,XX(100)
COMMON/UCOM1/IDEDP,IPAS,IENT,IPAS,IPCO,ISRFOL,ISTCO,ITOPA,
&JRU,JCMAC,MAC,NIQ,NMAC,NRANK,NTPT,ITALB(9),IDLEB(9),IDQU(9)
COMMON/UCOM2/PRINT,SPAGV,SPCON,SPUAGV,TTSLO,TTULSO,DLOM(9),
&DUMOM(9),DSTEM(9),NF(30),PARR(25,220),NNQ(30),ITRACK(9)
COMMON/UCOM3/ITCS(9),MACAQ(9),KT1M(9,100)
COMMON/UCOM4/PRINT,SPAGV,SPCON,SPUAGV,TTSLO,TTULSO,DLOM(9),
&DUMOM(9),DSTEM(9),NF(30),PARR(25,220),NNQ(30),ITRACK(9)
COMMON/UCOM5/NODEP,NPARTY(25),DUEDAT(25,30),JFOUT(25)
COMMON/UCOM7/UCRANE,IUCRANE,IULO,IUNLO,IAGV,IUAGV,IPAL

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
CHARACTER PRINT*2
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
C — BLOCK THAT DECIDES WHERE THE ENTITY CAME FROM —
C

IF(II.EQ.1) THEN
   IPAS=0
   IENT=0
   NIQ=NMAC
1005 CALL SELPART
   IF(JCMAC.GT.NNQ(20)) GO TO 1010
   IF(IENT.LT.NIQ) GO TO 1005
1010 XX(1)=1
   XX(4)=1
   IF(IPAS.EQ.0) XX(1)=2
   XX(2)=IPAS
   RETURN
ELSEIF(II.EQ.2) THEN
   IF(JRU.EQ.1) THEN
      PURANG=DRAND(1)
      ATRIB(9)=PURANG
   ELSE...
   ENDIF
   CALL FILEM(20,ATRIB)
   IF(NNQ(20).GE.1.AND.NNQ(22).EQ.0) THEN
      IDG=0
   END
DO 1015 ICE=1,NMAC
   IF(IDQU(ICE).GT.0) GO TO 1015
   IDQ=IDQ+1
1015 CONTINUE
   IPAS=0
   IENT=0
   NIQ=IDQ
1020 CALL SELPART
   IF(JCMAB.GT.NNQ(20)) GO TO 1025
   IF(IENT.LT.NIQ) GO TO 1020
1025 XX(1)=1
   XX(2)=IPAS
   IF(IPAS.EQ.0) XX(1)=2
   XX(4)=1
   RETURN
ELSE
   XX(1)=2
   XX(4)=1
   RETURN
ENDIF
ELSEIF(II.EQ.3) THEN
   IENT=0
   IPAS=0
   NIQ=IDQ
1030 CALL SELPART
   IF(JCMAB.GT.NNQ(20)) GO TO 1035
   IF(IENT.LT.NIQ) GO TO 1030
1035 XX(2)=IPAS
   XX(1)=1
   XX(4)=2
   IF(IPAS.EQ.0) XX(1)=2
   RETURN
ELSE
   XX(1)=2
   XX(4)=1
   RETURN
ENDIF
END

C
C --- ROUTINE TO SELECT PART AND SEND IT INTO THE SYSTEM ---
C
SUBROUTINE SELPART

COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,
&NCLNR,NCORR,NPRT,NNRUN,NSSET,NTAPE,SS(100),SSL(100),TNEXT,
&TNOW,XX(100)
COMMON/UCOM1/ICOM,IDOP,IPAS,IDQ,IENT,IPAS,IPCO,ISRFOL,ISTCO,ITOPA,
&JRU,JCMAB,MAQ,MAQ,NIQ,NMAC,NRANK,NTPT,INTQ(9),IDLEQ(9),IDQU(9)
COMMON/UCOM2/JPCRA,PRINT,SPAGV,SPCON,SPUAGV,TTSLO,TTUSLO,DLOM(9),
&DLOM(9),DSTM(9),NF(30),PARR(25,220),MNF(30),ITRACK(9)
COMMON/UCOM3/ITCS(9),MACAQ(9),KTM(9,100)
COMMON/UCOM4/FINTIM,IRUN,ITRUN,MAR0,MPCOUNT,TENFB,JPRPT(25)
COMMON/UCOM5/LCOUNT,NPARTY(25),DUEDAT(25,30),JFOUT(25)
COMMON/UCOM7/ICRANE,IUCRANE,IL0,ILN0,IA0V,IAVG,IPAL

C ------------------------------------------------------------------
C ------------------------------------------------------------------
C CHARACTER PRINT2
C C ------------------------------------------------------------------
C IENT=IENT+1
JCMAQ=0
IF(NNQ(20).EQ.0) RETURN
DO 1040 KPB=1,NMAC
     IDLEQ(KPB)=0
1040 CONTINUE
KPA=0
DO 1045 KP=1,NMAC
     IF(DQU(KP).GT.0) GO TO 1045
     KPA=KPA+1
     IDLEQ(KPA)=KP
1045 CONTINUE
ITER=0
1050 NST=0
     ITER=ITER+1
1055 CONTINUE
     DO 1060 NRANK=NST+1,NNQ(20)
         CALL COPY(NRANK,20,ATRIB)
         IF(ITER.EQ.2) GO TO 1065
         IF(ATRIB(1).EQ.0) GO TO 1060
     1065 I0PT=ATRIB(5)
         IRES=ATRIB(7)
         IF(NF(IRES).EQ.0) GO TO 1060
         NF(IRES)=NF(IRES)-1
         GO TO 1070
     1060 CONTINUE
     IF(ITER.LT.2) GO TO 1050
     RETURN
1070 IGA=0
     MAC=0
     DO 1075 IAB=1,9
         IALTQ(IAB)=0
         MACAQ(IAB)=0
1075 CONTINUE
     DO 1080 IAL=22,30
         IF(ATRIB(IAL).EQ.0) GO TO 1085
         IGA=IGA+1
         IALTQ(IQA)=ATRIB(IAL)
     1080 CONTINUE
1085 CONTINUE
     DO 1090 IQAC=1,NIQ
         IF(IAT(IAT).NE.IDLEQ(IQAC)) GO TO 1095
MAQ = MAQ + 1
MACAO(MAQ) = IDLEQ(IQAC)

1095 CONTINUE
1090 CONTINUE

IF (MAQ.EQ.0) THEN
   JCMAQ = JCMAQ + 1
   NF(IRES) = NF(IRES) + 1
   NST = NRANK
   GO TO 1055
ELSEIF (MAQ.EQ.1) THEN
   ICOM = MACAO(1)
   IDQU(ICOM) = 1
ELSE
   CALL SELRAND
ENDIF

CALL RMOVEINRANK, 20, ATRIB)

ATRIB(B) = ICOM
ATRIB(IDEOP + IOPT) = TNOW
ATRIB(10) = ITRACK(ICOM)

IF (PRINT.EQ.'0F') GO TO 1093
IPZ10 = ATRIB(2)
WRITE(B, 1091) TNOW, IPZ10

1091 FORMAT(10X, 'TIME = ', F10.4, ', PART # ', I3, ' HAS BEEN SELECTED T', \)
       WRITE(B, 1092) ICON, ITRACK(ICON)

1092 FORMAT('TO BE PROCESSED IN MACHINE ', I1, ', ON TRACK ', I1, ' FOR ', \)
       WRITE(B, 1094) IOPT

1094 FORMAT('OPERATION # ', I12)

1093 IPAS = IPAS + 1

CALL FILEM(21, ATRIB)
RETURN
END

C --- ROUTINE FOR SELECTING THE QUEUE AT RANDOM ---

C SUBROUTINE SELRAND

C COMMON BLOCK----------------------------------------

COMMON/SCOM1/ATRIB(100), DD(100), DDL(100), DTNOW, II, NFA, NSTOP, \& NCNR, NCNR, NPRNT, NNSET, NTAPE, SS(100), SSL(100), TNEXT, \& DTNOW, XX(100)
COMMON/UCOM1/ICOM, IDEOP, IDQ, IENT, IPAS, IPCO, ISPFO, ISTOP, ITOPA, \& IRRU, JCMAQ, MAQ, NIG, NMAG, NRANK, NTPT, IALTQ(9), IDLEG(9), IDGU(9)
COMMON/UCOM2/IPCRA, PRINT, SPAGV, SPCON, SPUAGV, SPSL, SPULSO, DLM(9), \& DULOM(9), DSTM(9), NF(30), PARR(25, 220), MFN(30), ITRACK(9)
COMMON/UCOM3/ITCS(9), MACAO(9), KTM(9, 100)
COMMON/UCOM4/FINTIM, IRUN, ITRUN, MARO, MPCOUNT, TENFB, JPRPT(25)
COMMON/UCOM5/LCOUNT, NPARTY(25), DUEAT(25, 30), JFOUT(25)
COMMON/UCOM7/ICRANE, IUCRANE, IULO, IUNLO, IAGV, IUAGV, IPAL

C -------------------------------------------------------

DIMENSION A(9)
CHARACTER PRINT#2
DO 1100 IN=1,NMAC
   A(IN)=0.0
1100 CONTINUE
DO 1110 IQ=1,MAQ
   A(IQ)=DLOM(MACAQ(IQ))+DULOM(MACAQ(IQ))
   IF(IQ.GT.1) GO TO 1115
   GMIN=A(IQ)
   MACAQ(IQ) = MANO
GO TO 1110
1115 IF (A(IQ).LT.GMIN) THEN
   GMIN=A(IQ)
   MACAQ(IQ) = MANO
ELSE
ENDIF
1110 CONTINUE
ICOM=MANO
IDQU(IC0M)=1
RETURN
END

C
C ********************************************************************************************************
C ROUTINE FOR RELEASING THE CART — EVENT 2
C ********************************************************************************************************

SUBROUTINE RELAGVL

CHARACTER PRINT*2

KUTRA=ATRIB(10)
CALL FREE(KUTRA+46,1)
CALL FREE(14,1)
IF(PRINT.EQ.'OF') RETURN
NWRITE(8,1116)TN0W
1116 FORMAT(lOX,'TIME = ',F10.4,' LOADING AGV IS RELEASED AT THE ' ,
   &NWRITE(8,1117)

C ********************************************************************************************************
C ROUTINE FOR RELEASING THE CART — EVENT 2
C ********************************************************************************************************

SUBROUTINE RELAGVL

CHARACTER PRINT*2

KUTRA=ATRIB(10)
CALL FREE(KUTRA+46,1)
CALL FREE(14,1)
IF(PRINT.EQ.'OF') RETURN
NWRITE(8,1116)TN0W
1116 FORMAT(lOX,'TIME = ',F10.4,' LOADING AGV IS RELEASED AT THE ' ,
   &NWRITE(8,1117)
C ROUTINE FOR CAPTURING THE TOOLS AS PART ENTERS THE SYSTEM -- EVENT 3
C ***********************************************************
SUBROUTINE TOOLCAPT
C ***********************************************************
CHARACTER PRINT*2
MACH=ATRIB(8)
ITCS(MACH)=0
DO 1120 JT=31,40
  IF(ATRIB(JT).EQ.0.0) GO TO 1125
  ITONE=ATRIB(JT)
  DO 1130 JTA=1,100
    IF(KTM(MACH,JTA).EQ.ITONE) GO TO 1120
  1130 CONTINUE
  ITCS(MACH)=ITCS(MACH)+1
1120 CONTINUE
1125 CONTINUE
IF(PRINT.EQ.'OF') RETURN
IPW=ATRIB(2)
WRITE(8,1126)IPW,ITCS(MACH),MACH
1126 FORMAT(20X,'PART ',13,' NEEDS ',12,' TOOLS AT MACHINE ',11) RETURN
END
C ***********************************************************
C ROUTINE FOR FREEING THE INPUT BUFFER -- EVENT 4
C ***********************************************************
SUBROUTINE FREEBUF
COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,
&NCLNR,NCDR,NPRINT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,
&TNOW,XX(100)
COMMON/UCOM1/ICOM,IDEOP,IDQ,IENT,IPAS,IPCO,ISRFOL,ISTCO,ITOA,
&JRU,JCMAQ,MAQ,NIQ,NMAC,NRANK,NTPT,IALTQ(9),IDLEQ(9),IDQU(9)
COMMON/UCOM2/IPCRA,PRINT,SPAGV,SPCON,SPUAGV,TTSLO,TTULSO,DLOM(9),
&DLUOM(9),DSTM(9),NF(30),PARR(25,220),MNF(30),ITRACK(9)
COMMON/UCOM3/ITCS(9),MACAQ(9),KTM(9,100)
COMMON/UCOM4/FINTIM,IRUN,ITRAN,MARG,MCOUNT,TFMB,IPRPT(25)
COMMON/UCOM5/ICOUNT,NPRTY(25),DUEAT(25,30),JFOUT(25)
COMMON/UCOM7/IUCRANE,IUCRANE,ICRANE,IU0LO,IU0ND,IAVG,IAVGY,IPAL
C ---------------------------------------------------------
C COMMON BLOCK---------------------------------------------
COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,
&NCLNR,NCDR,NPRINT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,
&TNOW,XX(100)
COMMON/UCOM1/ICOM,IDEOP,IDQ,IENT,IPAS,IPCO,ISRFOL,ISTCO,ITOA,
&JRU,JCMAQ,MAQ,NIQ,NMAC,NRANK,NTPT,IALTQ(9),IDLEQ(9),IDQU(9)
COMMON/UCOM2/IPCRA,PRINT,SPAGV,SPCON,SPUAGV,TTSLO,TTULSO,DLOM(9),
&DLUOM(9),DSTM(9),NF(30),PARR(25,220),MNF(30),ITRACK(9)
COMMON/UCOM3/ITCS(9),MACAQ(9),KTM(9,100)
COMMON/UCOM4/FINTIM,IRUN,ITRAN,MARG,MCOUNT,TFMB,IPRPT(25)
COMMON/UCOM5/ICOUNT,NPRTY(25),DUEAT(25,30),JFOUT(25)
COMMON/UCOM7/IUCRANE,IUCRANE,ICRANE,IU0LO,IU0ND,IAVG,IAVGY,IPAL
C ---------------------------------------------------------
C ROUTINE TO RELEASE MULTIPLE RESOURCES -- EVENT 5
C

SUBROUTINE RELFIXT

COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,
& NCLRNR,NCNRD,NPANT,NNPRN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,
& &TNOW,XX(100)
COMMON/UCOM1/ICOM,IDEOP,IFQ,IPAS,IPCO,ISRFOL,ISTCQ,ITOPA,
& JRU,JCMQ,MAQ,NIO,NMAC,NNANK,NRANK,NTPT,IALTQ(9),IDLEQ(9),IDOQ(9)
COMMON/UCOM2/JPCRAl,PRINT,SPAGV,SPCON,SPUAGV,TTSL0,TTULSO,DLOM(9),
& &DULOM(9),DSTM(9),NF(30),PARR(25,220),MNF(30),ITRACK(9)
COMMON/UCOM7/ITCS(9),MACAQ(9),KTM(9,100)
COMMON/UCOM4/FINTIM,IRUN,ITRUN,MRAD,MPCOUNT,TENFB,JPRPT(25)
COMMON/UCOM5/LCOUNT,NPARTY(25),DUEAT(25,30),JFOUT(25)
COMMON/UCOM7/ICRANE,IUCRANE,IULO,IIUNLO,IAGV,IIAAGV,IPAL

C

C —— RELEASING THE FIXTURE ——

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SUBROUTINE REENTER

COMMON/SCOM1/ATRIB(100), DD(100), DL(100), DNOW, II, NFA, MSTP,
& NCLNR, NCORD, NPRNT, NNRUN, NSET, NTPE, SS(100), SSL(100), TNEXT,
& TNOW, XX(100)
COMMON/UCOM1/ICOM, IDOP, IDQ, IENT, IPAS, IPCO, ISRFOL, ISTCO, ITOPA,
& JR, JCMAG, MAQ, MAC, MFRANK, MPT, IALTQ(9), IDEQ(9), IDQ(9)
COMMON/UCOM2/JPCRA, PRINT, SPAGV, SPCON, SPUAGV, TTSL0, TTUL50, DLON(9),
& DULON(9), DSTM(9), NF(30), PARR(25, 220), MTF(30), ITF(9)
COMMON/UCOM3/IICS(9), MACAG(9), KTM(9, 100)
COMMON/UCOM4/ITOS, IRUN, ITRUN, MAV, MPCOUNT, TENVB, JPRPT(25)
COMMON/UCOM5/LCOUNT, NPARTY(25), DUEDAT(25, 30), JFOUT(25)
COMMON/UCOM7/IERE, UIERE, UILO, IUNLO, IAGV, IAGV, IPAL

CHARACTER PRINT*2
EXTERNAL FINSTAT

JC0PT=ATRIB(5)
ATRIB(4)=ATRIB(4)-1.
ATRIB(IDOP+JC0PT)=ATRIB(IDOP+JC0PT)
ATRIB(5)=ATRIB(5)+1.
IF(ATRIB(4).EQ.0.0) GO TO 1140
DO 1145 IRE=22,40
ATRIB(IRE)=0.0
1145 CONTINUE

C --- SEGMENT FOR RE-ENTERING THE SYSTEM ---

C JRT=ATRIB(3)
JCR1=21
JCR2=17
JAR=ATRIB(5)
JCR3=JAR+JCR1-JCR2
ATRIB(6)=PARR(JRT, JCR3)
ATRIB(7) = PARR(JRT, JCR3+1)
DO 1150 JART = 22, 40
   ATRIB(JART) = PARR(JRT, JCR3+2)
   JCR3 = JCR3 + 1
1150 CONTINUE

II = 2
RETURN

C
C --- SEGMENT FOR COLLECTING DATA AS PART GOES OUT OF THE SYSTEM ---
C
1140 II = 4
MPCOUNT = MPCOUNT + 1
IPTN = ATRIB(3)
IPW3 = ATRIB(2)
IF (PRINT.EQ.'OF') GO TO 1144
WRITE(I(1141)) TNOW, IPW3
1141 FORMAT('TIME = ', F10.4, ' PART # ', I3, ' BELONGING TO PART ', \)
      WRITE(I(1142)) IPTN
1142 FORMAT('TYPE ', 12, ' HAS FINISHED ALL ITS OPERATIONS ')
WRITE(I(1143)) MPCOUNT
1143 FORMAT('NUMBER OF PARTS THAT HAVE LEFT THE SYSTEM = ', I3)
1144 NPARTY(IPTN) = NPARTY(IPTN) + 1
IF (N PARTY(IPTN).EQ. PARR(IPTN, 2)) THEN
   DUEDAT(IPTN, IRUN) = TNOW
   LCOUNT = LCOUNT + 1
   JFOUT(IPTN) = LCOUNT
ELSE
ENDIF
IF (TNOW.EQ.TENFB) THEN
   GO TO 1155
ELSE
IDQ = 0
IF (NNQ(20).GE.1.AND.NNQ(22).EQ.0) THEN
   DO 1160 IX = 1, NMAC
      IF (IDQU(DX).GT.0) GO TO 1160
      IDQ = IDQ + 1
1160 CONTINUE
   CALL OPEN(2)
ELSE
ENDIF
ENDIF
1155 CONTINUE
IF (MPCOUNT.EQ.ITOPA) THEN
   FINTIM = TNOW
   CALL FINSTAT
   RETURN
ELSE
   RETURN
ENDIF
END
C **********************************************************************
C ROUTINE FOR READJUSTMENT OF THE ATTRIBUTE ARRAY -- EVENT 7
C **********************************************************************

SUBROUTINE REATRIB

COMMON/SCOM1/ATRIB(100), DD(100), DDL(100), DTNOW, II, MFA, MSTOP,
& NCLNR, NCRDR, NPRINT, NNRUN, NNSET, NTAPE, SS(100), SSL(100), TNEXT,
& TNOW, XX(100)
COMMON/UCOM1/ICOM, IDEOP, I00, IENT, IPAS, IPCO, IRSFOL, ISTCO, ITOPA,
& JRU, JCMAG, MAQ, NIG, NMAC, NRANK, NTPT, IALTQ(9), IDLEQ(9), IDQ(9),
& DULM(9), DSTM(9), NF(30), PARR(25, 220), MNF(30), ITRACK(9)
COMMON/UCOM5/ITCS(9), MACA(9), KTM(9, 100)
COMMON/UCOM4/FINTIM, IRUN, ITRUN, MARO, MPCOUNT, TENFB, JPRPT(25)
COMMON/UCOM7/LCOUNT, NPARTY(25), DUEBAT(25, 30), JFOUT(25)
COMMON/UCOM7/ICRANE, IUCRANE, IULO, IUNLO, IAGV, IUAGV, IPAL

CHARACTER PRINT*2

DO 1165 IA=1,100
ATRIB(IA)=0.0
1165 CONTINUE
RETURN
END

C **********************************************************************
C ROUTINE FOR PLOTTING THE DATA EVENT 8
C **********************************************************************

SUBROUTINE PLOTFACT

COMMON/SCOM1/ATRIB(100), DD(100), DDL(100), DTNOW, II, MFA, MSTOP,
& NCLNR, NCRDR, NPRINT, NNRUN, NNSET, NTAPE, SS(100), SSL(100), TNEXT,
& TNOW, XX(100)
COMMON/UCOM1/ICOM, IDEOP, I00, IENT, IPAS, IPCO, IRSFOL, ISTCO, ITOPA,
& JRU, JCMAG, MAQ, NIG, NMAC, NRANK, NTPT, IALTQ(9), IDLEQ(9), IDQ(9),
& DULM(9), DSTM(9), NF(30), PARR(25, 220), MNF(30), ITRACK(9)
COMMON/UCOM5/ITCS(9), MACA(9), KTM(9, 100)
COMMON/UCOM4/FINTIM, IRUN, ITRUN, MARO, MPCOUNT, TENFB, JPRPT(25)
COMMON/UCOM7/LCOUNT, NPARTY(25), DUEBAT(25, 30), JFOUT(25)
COMMON/UCOM7/ICRANE, IUCRANE, IULO, IUNLO, IAGV, IUAGV, IPAL

CHARACTER PRINT*2

IF (TNOW.GE.FINTIM) THEN
XX(9)=2
RETURN
ELSE
IF (IRUN.GT.1) GO TO 1199
ENDIF

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SUBROUTINE FINSTAT

C - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
C —  INITIALISATION OF ALL ARRAYS IN THE FIRST RUN —
C

IF(IRUN.GT.I) GO TO 3005
DO 3010 IDCARX=1,9
   DO 3015 IDCARY=1,30
      UTIMAC(IDCARX,IDCARY)=0.0
3015 CONTINUE
3010 CONTINUE

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SPAN(IDCARY) = 0.0
SCHRA(IDCARY) = 0.0
3015 CONTINUE
3010 CONTINUE
   DO 3020 IDCARY = 1, 30
      DO 3025 IDCARX = 1, 25
         JDF(IDCARX, IDCARY) = 0
      3025 CONTINUE
   DO 3030 IDCARX = 1, 7
      UTIRES(IDCARX, IDCARY) = 0.0
   3030 CONTINUE
   DO 3035 IDCARX = 1, 30
      UTIFIX(IDCARX, IDCARY) = 0.0
   3035 CONTINUE
3020 CONTINUE

C
C   --- ASSIGNING NUMBER OF RESOURCES TO ARRAY ---
C
KRES(1) = NCRANE
KRES(2) = NUCRANE
KRES(3) = NUL0
KRES(4) = NUNLO
KRES(5) = NAGV
KRES(6) = NUA GV
KRES(7) = NPAL

C
C   --- ACTUAL COLLECTION OF DATA FOR EACH RUN IN THIS SEGMENT ---
C
3005 SPAN(IRUN) = TNON
   SCHRA(IRUN) = SPAN(IRUN) / ITOPA

C
C   --- MACHINE UTILIZATION DATA COLLECTION ---
C
   DO 3040 IDCMAC = 1, NMAC
      UTIMAC(IDCMAC, IRUN) = TTAVG(IDCMAC)
   3040 CONTINUE

C
C   --- RESOURCE UTILIZATION DATA COLLECTION ---
C
   DO 3045 IDCRES = 1, 7
      UTIRES(IDCRES, IRUN) = RRAVG(IDCRES + 9) / KRES(IDCRES)
   3045 CONTINUE

C
C   --- FIXTURE UTILIZATION DATA COLLECTION ---
C
   DO 3050 IDCFIX = 1, 30
      IF (MNFD(IDCFIX), EQ, 0) GO TO 3055
      UTIFIX(IDCFIX, IRUN) = RRAVG(IDCFIX + 16) / MNF(IDCFIX)
   3050 CONTINUE

C
C --- DUE DATE COLLECTION ---
C
3055 CONTINUE
   DO 3060 JG=1,NTPT
      JDF(JG,IRUN)=JFOUT(JG)
3060 CONTINUE
   IF(IRUN.LT.IRUN) RETURN
C
C --- AVERAGES FOR CALCULATED IN THIS SEGMENT ---
C
WRITE(*,3065)
3065 FORMAT(/,10X,'PLEASE WAIT - PRINTING ON LINE PRINTER'
     \)
WRITE(8,3070)
3070 FORMAT(/)
   WRITE(8,3071)CHAR(27),CHAR(12)
3071 FORMAT(2A1)
WRITE(8,3075)
3075 FORMAT(10X,'***************************************')
   WRITE(8,3080)ITRUN
3080 FORMAT(/,11X,'PRINTOUT AFTER ',12,' RUNS OF THE SIMULATION '
     \)
   WRITE(8,3085)
3085 FORMAT(//,11,3X,'Run #     Makespan (mins)     Avg.Time / Part')
WRITE(8,3090)
3090 FORMAT(11,3X,'---------------------------------')
   DO 3095 JRUN=1,ITRUN
      WRITE(8,3100)JRUN,SPAN(JRUN),SCHRA(JRUN)
3100 FORMAT(13X,I3,6X,F11.4,15X,F7.3)
   SUM1=SUM1+SPAN(JRUN)
   SUM2=SUM2+SCHRA(JRUN)
3095 CONTINUE
   AVSPAN=SUM1/ITRUN
   AVSCHRA=SUM2/ITRUN
   IF(ITRUN.EQ.1) GO TO 3105
5D10 JRUN=1,ITRUN
      SQDIF1=SQDIF1+(ABS(SPAN(JRUN)-AVSPAN))**2
      SQDIF2=SQDIF2+(ABS(SCHRA(JRUN)-AVSCHRA))**2
3105 CONTINUE
   VARSPAN=SQDIF1/(ITRUN-1)
   VARSCHRA=SQDIF2/(ITRUN-1)
WRITE(8,3115)AVSPAN,AVSCHRA
3115 FORMAT(14X,'Avg ',4X,F11.4,15X,F7.3)
   IF(ITRUN.EQ.1) GO TO 3120
   WRITE(8,3125)VARSPAN,VARSCHRA
3125 FORMAT(14X,'Var ',4X,F11.4,15X,F7.3)

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C
C --- MACHINE UTILIZATIONS ---
C
3120 CONTINUE
   WRITE(8,3122)
3122 FORMAT(/)
   WRITE(8,3071)CHAR(27),CHAR(12)
   DO 3130 JINT=1,9
      SUMAC(JINT)=0.0
      AVUMAC(JINT)=0.0
      SDIF(JINT)=0.0
      VARMAC(JINT)=0.0
   3130 CONTINUE
   WRITE(8,3135)
3135 FORMAT(/,10X,'UTILIZATION OF MACHINES :')
   WRITE(8,3140)
3140 FORMAT(/,T11,3X,'Run ',I1,'
   DO 3145 JM=1,NMAC
      WRITE(8,3150)JM
   3145 CONTINUE
   WRITE(8,3155)
3155 FORMAT(/,T11,3X,'- - - -',
   DO 3160 JM=1,NMAC
      WRITE(8,3165)
   3160 CONTINUE
   DO 3166 KR=1,ITRUN
      WRITE(8,3170)KR
   3166 CONTINUE
   DO 3185 KR=1,ITRUN
      DO 3190 JM=1,NMAC
         SUMAC(JM)=SUMAC(JM)+UTIMAC(JM,KR)
      3190 CONTINUE
   3185 CONTINUE
   DO 3195 JM=1,NMAC
      AVUMAC(JM)=SUMAC(JM)/ITRUN
   3195 CONTINUE
   IF(ITRUN.EQ.1) GO TO 3250
   DO 3200 KR=1,ITRUN
      DO 3205 JM=1,NMAC
         SDIF(JM)=SDIF(JM)+(ABS(AVUMAC(JM)-UTIMAC(JM,KR)))**2
      3205 CONTINUE
   3200 CONTINUE
   DO 3210 JM=1,NMAC
      
}
VARMAC(JM) = SDIF(JM) / (ITRUN - 1)

3210 CONTINUE
3250 WRITE(8,3155)
   DO 3215 JM = 1, NMAC
      WRITE(8,3165)
   3215 CONTINUE
   WRITE(8,3220)
   DO 3220 JM = 1, NMAC
      WRITE(8,3230) AVUMAC(JM)
   3220 CONTINUE
   IF(ITRUN.EQ.1) GO TO 3255
   WRITE(8,3235)
   DO 3240 JM = 1, NMAC
      WRITE(8,3245) VARMAC(JM)
   3240 CONTINUE
   C
   C --- RESOURCE UTILIZATIONS ---
   C
3255 CONTINUE
3257 FORMAT(/,10X,'UTILIZATION OF THE RESOURCES:')
   WRITE(8,3270)
3260 FORMAT(/,11X,'Run I Crane Uncrane Load Uload',/)
   WRITE(8,3275)
   FORMAT(' AGV-L AGV-UL Pallet',/)
   WRITE(8,3280)
   FORMAT(/,11X,'- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - ',/)
   WRITE(8,3285)
   FORMAT('- - - - - - - - - - - - - - - - - - - - - - ',/)
   DO 3290 KR = 1, ITRUN
      WRITE(8,3295) KR
      DO 3300 LR = 1, 7
         WRITE(8,3305) UTIRES(LR,KR)
      3300 CONTINUE
CONTINUE
WRITE(8,3280)
WRITE(8,3285)
DO 3310 KR=1,ITRUN
   DO 3315 JM=1,7
      SUMAC(JM)=SUMAC(JM)+UTIRES(JM,KR)
   CONTINUE
3315 CONTINUE
3310 CONTINUE
DO 3320 JM=1,7
   AVUMAC(JM)=SUMAC(JM)/ITRUN
3320 CONTINUE
IF(ITRUN.EQ.1) GO TO 3360
DO 3325 KR=1,ITRUN
   DO 3330 JM=1,NMAC
      SDIF(JM)=SDIF(JM)+(ABS(AVUHAC(JM)-UTIRES(JM,KR)))*1.2
   CONTINUE
3325 CONTINUE
DO 3335 JM=1,7
   VARMAC(JM)=SDIF(JM)/(ITRUN-1)
3335 CONTINUE
3360 WRITE(8,3220)
3340 FORMAT(' ',F7.5,' ',")
3345 CONTINUE
IF(ITRUN.EQ.1) GO TO 3365
WRITE(8,3235)
DO 3350 JM=1,7
   WRITE(8,3355)AVUMAC(JM)
3355 FORMAT(' ',F7.5,' ',")
3350 CONTINUE
C
C --- FIXTURE UTILIZATIONS ---
C
3360 WRITE(8,3370)
3370 FORMAT(///,10X,'UTILIZATION OF FIXTURES : ',/
   DO 3375 JF=1,30
      IF(MNF(JF).EQ.0) GO TO 3380
      SUMF=0.0
      FDIF=0.0
      DO 3385 JR=1,ITRUN
         SUMF=SUMF+UTIFIX(JF,JR)
      CONTINUE
3385 CONTINUE
      AVFIX=SUMF/ITRUN
      IF(ITRUN.EQ.1) GO TO 3400
      DO 3390 JR=1,ITRUN
         FDIF=FDIF+(ABS(AVFIX-UTIFIX(JF,JR)))*1.2
      CONTINUE
3390 CONTINUE
      VARFIX=FDIF/(ITRUN-1)
CONTINUE
C
C --- DUE DATES FOR THE PART TYPES ---
C
3380 CONTINUE
WRITE(8,3381)
3381 FORMAT('DUE DATES FOR THE PART TYPES:')
WRITE(8,3405)
3405 FORMAT('DUE DATES FOR THE PART TYPES:')
3410 FORMAT('Run # ',I2,'
DO 3415 IPM=1,NTPT
WRITE(8,3420)IPM
3420 FORMAT('Type',I2,' ',I2,'
3415 CONTINUE
WRITE(8,3425)
3425 FORMAT('-------'
DO 3430 IPM=1,NTPT
WRITE(8,3435)
3435 FORMAT('-------'
3430 CONTINUE
DO 3440 JR=1,ITRUN
WRITE(8,3445)JR
3445 FORMAT(' ',I2,'
DO 3450 IPM=1,NTPT
WRITE(8,3455)IPM,JR
3455 FORMAT(F10.3,' - ',I2,'
3450 CONTINUE
WRITE(8,3475)
3475 FORMAT('=============================================')
WRITE(8,3480)
3480 FORMAT('===================================================')
WRITE(8,3491)
3491 FORMAT('')
WRITE(8,3492)CHAR(27),CHAR(12)
3492 FORMAT(2A1)
DO 3490 JUTE=1,24
WRITE(*,3495)CHAR(7)
3495 FORMAT(IX,'ALL THE RUNS YOU REQUESTED ARE OVER '
PAUSE 'PRESS CTRL-BREAK KEY TO STOP THE PROGRAM'
RETURN
END
APPENDIX-C

SAMPLE SCREEN DISPLAYS OF THE SIMULATION MODEL
SCHEDULING RULES THAT ARE AVAILABLE:

1. Random selection rule
2. Fewest operations remaining
3. Most operations remaining
4. Shortest processing time
5. Longest processing time

ENTER THE SCHEDULING RULE YOU NEED:  2

ENTER THE TOTAL NUMBER OF RUNS:  20

DO YOU WANT TO TRACE THE SIMULATION [ Y OR N ]?  N

ENTER NAME OF FILE THAT STORES THE PART DATA:  PARTDATA.PAR

ENTER NAME OF FILE THAT STORES PRIORITY DATA:  PRIORITY.PRI

ENTER NAME OF FILE THAT STORES LAYOUT DATA:  DISTANCE.LAY

ENTER NAME OF FILE THAT STORES MHS TIME DATA:  TIMEDATA.TIM

DO YOU WANT A PRINT OUT OF THE INPUT DETAILS [ Y OR N ]?  N
DETAILS OF THE RESOURCES TO BE ENTERED

ENTER THE NUMBER OF LOADING CRANES AVAILABLE — 1
ENTER THE NUMBER OF UNLOADING CRANES AVAILABLE — 1
ENTER THE NUMBER OF LOADERS AVAILABLE — 1
ENTER THE NUMBER OF UNLOADERS AVAILABLE — 1
ENTER THE NUMBER OF LOADING AGVs AVAILABLE — 1
ENTER THE NUMBER OF UNLOADING AGVs AVAILABLE — 5
ENTER THE NUMBER OF LANES IN THE SYSTEM — 2

ENTER THE NUMBER OF FIXTURE TYPES USED — 6
QUANTITY OF FIXTURE TYPE 1 AVAILABLE — 2
QUANTITY OF FIXTURE TYPE 2 AVAILABLE — 1
QUANTITY OF FIXTURE TYPE 3 AVAILABLE — 2
QUANTITY OF FIXTURE TYPE 4 AVAILABLE — 1
QUANTITY OF FIXTURE TYPE 5 AVAILABLE — 1
QUANTITY OF FIXTURE TYPE 6 AVAILABLE — 1
APPENDIX-D

COMPUTER PROGRAM LISTING OF SLAM NETWORK PROGRAM
NETWORK PORTION OF THE MODEL

Fewest Operations Remaining [ FOPR ] rule used

Physical limitations of the simulation model :

(i) Maximum number of machines--------9
(ii) Maximum number of parts that could be in the central parts storage at any point in time--------250
(iii) Maximum number of fixture types-------30
(iv) Maximum number of tool types--------100
(v) Maximum number of part types--------25

For each part type

(i) Maximum number of alternate machines available for an operation - 9 (But this could be less depending on the actual number of machines used in the system)
(ii) Maximum number of operations - 10
(iii) Maximum number of tools per operation - 10

Resource details - [ See resource blocks ]

(i) Machines are treated as resources (Resource 1 to 9)
(ii) The MHS are treated as resources (Resource 10 to 16)
(iii) Fixture types are treated as resources (Resource 17 to 46)
(iv) Tracks on which the machines are located are treated as resources

Loading tracks - Resource 47 to 51
Unloading tracks - Resource 52 to 56

The initial quantities of these resources are made zero as can be seen in the resource block. The initialisation routine alters the value of these resources as the program is run.

CONTROL STATEMENTS

GEN,RAVI THIRUVENGADAM,THESIS,06/10/86,30,N,N,,N,NO;
LIMITS,26,40,250;
PRIORITY/20,LVF(4);
SEEDS,43521343(1);
TIMST,XX(11),MACH1 UTIL;
TIMST,XX(12),MACH2 UTIL;
TIMST,XX(13),MACH3 UTIL;
TIMST,XX(14),MACH4 UTIL;
TIMST,XX(15),MACH5 UTIL;
TIMST,XX(16),MACH6 UTIL;
TIMST,XX(17),MACH7 UTIL;
TIMST,XX(18),MACH8 UTIL;
TIMST,XX(19),MACH9 UTIL;

;-------------------------------;
;NETWORK STATEMENTS i.e; THE NODES
;--------------------------------

NETWORK;

;RESOURCES BLOCK
;-----------------

;MACHINES AS RESOURCES
RESOURCE/MACH1(0),1;
RESOURCE/MACH2(0),2;
RESOURCE/MACH3(0),3;
RESOURCE/MACH4(0),4;
RESOURCE/MACH5(0),5;
RESOURCE/MACH6(0),6;
RESOURCE/MACH7(0),7;
RESOURCE/MACH8(0),8;
RESOURCE/MACH9(0),9;

;COMMON RESOURCES
RESOURCE/CRANE(0),22;
RESOURCE/UNCRANE(0),23;
RESOURCE/LOADER(0),22;
RESOURCE/UNLOADER(0),23;
RESOURCE/AGVL(0),22;
RESOURCE/UAGV(0),23;
RESOURCE/PALLET(0),22;

;FIXTURES AS RESOURCES
RESOURCE/FIXT1(0),22;
RESOURCE/FIXT2(0),22;
RESOURCE/FIXT3(0),22;
RESOURCE/FIXT4(0),22;
RESOURCE/FIXT5(0),22;
RESOURCE/FIXT6(0),22;
RESOURCE/FIXT7(0),22;
RESOURCE/FIXT8(0),22;
RESOURCE/FIXT9(0),22;
RESOURCE/FIXT10(0),22;
RESOURCE/FIXT11(0),22;
RESOURCE/FIXT12(0),22;
RESOURCE/FIXT13(0),22;

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RESOURCE/FIXT14(0),22;
RESOURCE/FIXT15(0),22;
RESOURCE/FIXT16(0),22;
RESOURCE/FIXT17(0),22;
RESOURCE/FIXT18(0),22;
RESOURCE/FIXT19(0),22;
RESOURCE/FIXT20(0),22;
RESOURCE/FIXT21(0),22;
RESOURCE/FIXT22(0),22;
RESOURCE/FIXT24(0),22;
RESOURCE/FIXT25(0),22;
RESOURCE/FIXT26(0),22;
RESOURCE/FIXT27(0),22;
RESOURCE/FIXT28(0),22;
RESOURCE/FIXT29(0),22;
RESOURCE/FIXT30(0),22;

;TRACKS AS RESOURCES
RESOURCE/TRAC1(0),25;
RESOURCE/TRAC2(0),25;
RESOURCE/TRAC3(0),25;
RESOURCE/TRAC4(0),25;
RESOURCE/TRAC5(0),25;
RESOURCE/TRAC6(0),23;
RESOURCE/TRAC7(0),23;
RESOURCE/TRAC8(0),23;
RESOURCE/TRAC9(0),23;
RESOURCE/TRAC10(0),23;

;GATE BLOCKS
GATE/PILEUP,CLOSE,21;
GATE/INTOP,CLOSE,24;

;NODE DETAILS OF THE ENTIRE FLEXIBLE MANUFACTURING SYSTEM

CRE1 CREATE;
ASS1 ASSIGN,II=1,XX(3)=0;
EVE1 EVENT,1,1; Initial part input into system
ACT, XX(1) .EQ. 1, OPE1;
ACT, XX(1) .EQ. 2, DON;
ACT;
ACCU AWAIT(21), PILEUP;
ASS2 ASSIGN, XX(3) = XX(3) + 1;
ACT, XX(3) .EQ. XX(2), CLO1;
ACT, XX(3) .LT. XX(2), MULT;
CLO1 CLOSE, PILEUP;
ASS3 ASSIGN, XX(3) = 0;
MULT AWAIT(22), ALLOC(1);  Capturing multiple resources
;
*******************************************************************************
* SEGMENT - 2 *
*******************************************************************************
* THE ACTUAL ENTRY OF PARTS INTO THE SYSTEM AT THE LOADING STATION *
*******************************************************************************
;
ACT, USERF(1);
GOON;
ACT, UNFRM(2.0, 3.0, 1);
FCRA FREE, CRANE/1;
FLOA FREE, LOADER/1, 1;
AW25 AWAIT(25), ALLOC(2);  Waiting for track to clear
AS20 ASSIGN, XX(20) = XX(20) + 1;
ACT, USERF(2);  Increment total number in FMS by 1
ACT, USERF(3), EVE2;
SEPA GOON, 2;
ACT, EVE3;
ACT, USERF(3), EVE2;  Travel time for AGV to loading stn.
EVE2 EVENT, 2;  Release loading AGV, clearing track
TERM;
EVE3 EVENT, 3;  Capturing the tools
;
*******************************************************************************
* SEGMENT - 3 *
*******************************************************************************
* ROUTING OF THE PART TO THE APPROPRIATE MACHINE FOR THE OPERATION TO BE DONE *
*******************************************************************************
;
GO01 GOON, 1;
ACT, ATRIB(B).EQ.1, BUF1;
ACT, ATRIB(B).EQ.2, BUF2;
ACT, ATRIB(B).EQ.3, BUF3;
ACT, ATRIB(B).EQ.4, BUF4;
ACT, ATRIB(B).EQ.5, BUF5;
ACT, ATRIB(B).EQ.6, BUF6;
ACT, ATRIB(B).EQ.7, BUF7;
ACT, ATRIB(B).EQ.8, BUF8;
ACT, ATRIB(B).EQ.9, BUF9;
Freeing the input buffer

Waiting time for tools from tool crib

Processing time on M/C 1

Processing time on M/C 2

Processing time on M/C 3

Processing time on M/C 4
6055 ASSIGN, XX(15) = 1;
ACT/5, ATRIB(6);
ASSIGN, XX(15) = 0;
ACT,,6060;

6066 ASSIGN, XX(16) = 1;
ACT/6, ATRIB(6);
ASSIGN, XX(16) = 0;
ACT,,6060;

6077 ASSIGN, XX(17) = 1;
ACT/7, ATRIB(6);
ASSIGN, XX(17) = 0;
ACT,,6060;

6088 ASSIGN, XX(18) = 1;
ACT/8, ATRIB(6);
ASSIGN, XX(18) = 0;
ACT,,6060;

6099 ASSIGN, XX(19) = 1;
ACT/9, ATRIB(6);
ASSIGN, XX(19) = 0;
ACT,,6060;

6060 GOON;
FREM FREE, ATRIB(8)/1,1; Release the M/C after processing

ACT,, ATRIB(8).EQ.1,QU10;
ACT,, ATRIB(8).EQ.2,QU11;
ACT,, ATRIB(8).EQ.3,QU12;
ACT,, ATRIB(8).EQ.4,QU13;
ACT,, ATRIB(8).EQ.5,QU14;
ACT,, ATRIB(8).EQ.6,QU15;
ACT,, ATRIB(8).EQ.7,QU16;
ACT,, ATRIB(8).EQ.8,QU17;
ACT,, ATRIB(8).EQ.9,QU18;
QU10 QUEUE(10),1,BLOCK,SEL;
QU11 QUEUE(11),1,BLOCK,SEL;
QU12 QUEUE(12),1,BLOCK,SEL;
QU13 QUEUE(13),1,BLOCK,SEL;
QU14 QUEUE(14),1,BLOCK,SEL;
QU15 QUEUE(15),1,BLOCK,SEL;
QU16 QUEUE(16),1,BLOCK,SEL;
QU17 QUEUE(17),1,BLOCK,SEL;
QU18 QUEUE(18),1,BLOCK,SEL;

SEL SELECT,LWF,, QU10,QU11,QU12,QU13,QU14,QU15,QU16,QU17,QU18;
ACT;
TRANSPORTATION OF THE PART BACK TO THE UNLOADING STATION FROM THE OUTPUT BUFFER OF THE MACHINE

AW23  AWAIT(23/1),ALLOC(3),BLOCK;
     ACT,USERF(5);  Travel time to unloading station
     AS26  ASSIGN,XX(20)=XX(20)-1;  Decrease total number in FMS by 1
     ACT,USERF(6);  Travel time for unloading crane
     GOON;
     ACT,UNFRM(1.0,2.0,1);  Unloading time unloading station
     FPAL  FREE,PALLET/1;
     FULO  FREE,UNLOADER/1;
     FRUG  FREE,UNCRANE/1;
     EVE5  EVENT,5;
     ACT,USERF(7);  Travel time to parts storage
     FUCR  FREE,UNCRANE/1;
     EVE6  EVENT,6,1;
     ACT,,II.EQ.2,EVE1;
     ACT,,II.EQ.4;
     TERM;

CRE2  CREATE;
BAIN  AWAIT(24),INTOP;
CL02  CLOSE,INTOP;
ASS4  ASSIGN,II=3;
     ACT,,II.EQ.3,EVE1;
EVE7  EVENT,7;
     ACT,,BAIN;
     CREATE;
EVE8  EVENT,8,1;
     ACT,,10.0,XX(9).EQ.1,EVEB;
     ACT,,XX(9).EQ.2,TER;
OPE1  OPEN,PILEUP,1;
     ACT,,XX(4).EQ.1,TER;
     ACT,,XX(4).EQ.2,EVE7;
DON  GOON,1;
     ACT,,XX(4).EQ.1,TER;
ACT,,XX(4).EQ.2,EVE7;
TER TERM;
END;
SIMULATE;
SEEDS,-43521343(1);
SIMULATE;
SEEDS,79732799(1);
SIMULATE;
SEEDS,-79732799(1);
SIMULATE;
SEEDS,34349213(1);
SIMULATE;
SEEDS,-34349213(1);
SIMULATE;
SEEDS,56231987(1);
SIMULATE;
SEEDS,-56231987(1);
SIMULATE;
SEEDS,2356971(1);
SIMULATE;
SEEDS,-2356971(1);
SIMULATE;
SEEDS,9028303(1);
SIMULATE;
SEEDS,-9028303(1);
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SEEDS,3458341(1);
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SEEDS,87678623(1);
SIMULATE;
SEEDS,-87678623(1);
SIMULATE;
SEEDS,73451239(1);
SIMULATE;
SEEDS,-73451239(1);
SIMULATE;
SEEDS,3459211235(1);
SIMULATE;
SEEDS,-3459211235(1);
SIMULATE;
SEEDS,62467831(1);
SIMULATE;
SEEDS,-62467831(1);
SIMULATE;
SEEDS, 987313123(1);
SIMULATE;
SEEDS, -987313123(1);
SIMULATE;
SEEDS, 798324125(1);
SIMULATE;
SEEDS, -798324125(1);
SIMULATE;
SEEDS, 32453241(1);
SIMULATE;
SEEDS, -32453241(1);
FIN;
APPENDIX-E

SAMPLE TRACE OF THE SIMULATION
TRACE OF RUN 1 OF THE SIMULATION

TIME = 0.0000 PART 2 HAS BEEN SELECTED TO BE PROCESSED IN MACHINE 2 ON TRACK 2 FOR OPERATION 1
TIME = 0.0000 PART 1 HAS BEEN SELECTED TO BE PROCESSED IN MACHINE 1 ON TRACK 1 FOR OPERATION 1
TIME = 0.0000 PART 2 SELVES THE LOADING CRANE, LOADING AVG, LOADER, PALLET AND FIXTURE
TIME = 0.0000 PART 2 TRANSPORTED FROM THE CPS TO THE LOADING STATION - TRAVEL TIME = 2.000
TIME = 4.0000 PART 1 SELVES THE LOADING CRANE, LOADING AVG, LOADER, PALLET AND FIXTURE
TIME = 4.0000 PART 1 TRANSPORTED FROM THE CPS TO THE LOADING STATION - TRAVEL TIME = 4.000
TIME = 4.0000 PART 2 TRANSPORTED FROM LOADING STATION TO MACHINE 2 - TRAVEL TIME = 0.000
LOADING AVG CARRYING PART 2 MOVING ON LOADING TRACK 2
TIME = 4.0000 PART 2 RELEASES CART AT MACHINE 2 - AVG TRAVEL TIME TO CPS = 0.000
EMPTY LOADING AVG MOVING ON LOADING TRACK 2
PART 2 MELLS 3 TOOLS FROM MACHINE 2
TIME = 4.0000 PART 2 LEAVING THE INPUT BUFFER OF MACHINE 2
TIME = 4.0000 PART 2 WAITS FOR TOOLS FROM THE TOOL CHUTE AT MACHINE 2 - WAITING TIME = 1.000
TIME = 5.0000 LOADING AVG IS RELEASED AT THE LOADING STATION
TIME = 10.0000 PART 1 TRANSPORTED FROM LOADING STATION TO MACHINE 1 - TRAVEL TIME = 0.000
LOADING AVG CARRYING PART 1 MOVING ON LOADING TRACK 1
TIME = 10.0000 PART 1 RELEASES CART AT MACHINE 1 - AVG TRAVEL TIME TO CPS = 0.000
EMPTY LOADING AVG MOVING ON LOADING TRACK 1
PART 1 MELLS 3 TOOLS FROM MACHINE 1
TIME = 10.0000 PART 1 LEAVING THE INPUT BUFFER OF MACHINE 1
TIME = 10.0000 PART 1 WAITS FOR TOOLS FROM THE TOOL CHUTE AT MACHINE 1 - WAITING TIME = 1.000
TIME = 11.0000 LOADING AVG IS RELEASED AT THE LOADING STATION
TIME = 19.0000 PART 2 SELVES THE UNLOADING AVG, UNLOADER, AND UNLOADING CRANE
TIME = 19.0000 PART 2 TRANSPORTED FROM MACHINE 2 TO UNLOADING STATION - TRAVEL TIME = 1.000
UNLOADING AVG CARRYING PART 2 MOVING ON UNLOADING TRACK 2
TIME = 20.0000 PART 2 WAITS FOR THE UNLOADING CRANE AT THE UNLOADING STATION - WAITING TIME = 1.000
TIME = 22.0000 PART 2 RELEASES FIXTURE
TIME = 23.0000 PART 2 TRANSPORTED FROM THE UNLOADING STATION TO THE CPS - TRAVEL TIME = 2.000
TIME = 25.0000 PART 1 SELVES THE UNLOADING AVG, UNLOADER, AND UNLOADING CRANE
TIME = 25.0000 PART 1 TRANSPORTED FROM MACHINE 1 TO UNLOADING STATION - TRAVEL TIME = 1.500
UNLOADING AVG CARRYING PART 1 MOVING ON UNLOADING TRACK 1
TIME = 25.0000 PART 2 BELONGING TO PART TYPE 2 HAS FINISHED ALL ITS OPERATIONS
NUMBER OF PARTS THAT HAVE LEFT THE SYSTEM = 1
TIME = 27.1000 PART 1 WAITS FOR THE UNLOADING CRANE AT THE UNLOADING STATION - WAITING TIME = 2.000
TIME = 30.1000 PART 1 RELEASES FIXTURE
TIME = 30.1000 PART 1 TRANSPORTED FROM THE UNLOADING STATION TO THE CPS - TRAVEL TIME = 2.000
TIME = 32.1000 PART 1 BELONGING TO PART TYPE 1 HAS FINISHED ALL ITS OPERATIONS
NUMBER OF PARTS THAT HAVE LEFT THE SYSTEM = 2
## OPERATION SHEET

### PART TYPE 1

<table>
<thead>
<tr>
<th>Optr</th>
<th>Operation Description</th>
<th>Tool</th>
<th>Time (mins)</th>
<th>Machines</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Rough mill top face</td>
<td>M1</td>
<td>24</td>
<td>1or2or5</td>
</tr>
<tr>
<td></td>
<td>Finish mill top face</td>
<td>M2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Drill 10 dia. holes (12)</td>
<td>D1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ream 10 dia. holes (12)</td>
<td>R1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>02</td>
<td>Rough mill bottom face</td>
<td>M1</td>
<td>24</td>
<td>1or2or5</td>
</tr>
<tr>
<td></td>
<td>Finish mill bottom face</td>
<td>M2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Drill 10 dia. holes (12)</td>
<td>D1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ream 10 dia. hole (12)</td>
<td>R1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>03</td>
<td>Rough mill side face</td>
<td>M3</td>
<td>18</td>
<td>3or4</td>
</tr>
<tr>
<td></td>
<td>Finish mill side face</td>
<td>M4</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Drill 10 dia. holes (8)</td>
<td>D1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ream 10 dia. holes (8)</td>
<td>R1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### OPERATION SHEET

**PART TYPE 2**

<table>
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<th>Tool</th>
<th>Time (mins)</th>
<th>Machines</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Rough mill top face</td>
<td>M5</td>
<td>31</td>
<td>1 or 2 or 5</td>
</tr>
<tr>
<td></td>
<td>Finish mill top face</td>
<td>M6</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Drill 8 dia. holes (16)</td>
<td>D2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ream 8 dia. holes (16)</td>
<td>R2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Countersink 8 dia. holes (16)</td>
<td>CS1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Diagram of Part Type 2](image-url)
# OPERATION SHEET

## PART TYPE 3

<table>
<thead>
<tr>
<th>Opn</th>
<th>Operation Description</th>
<th>Tool</th>
<th>Time (mins)</th>
<th>Machines</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Rough mill bottom face</td>
<td>M7</td>
<td>6</td>
<td>1or2or5</td>
</tr>
<tr>
<td></td>
<td>Finish mill bottom face</td>
<td>M8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>02</td>
<td>Rough mill top face</td>
<td>M7</td>
<td>23</td>
<td>3or4</td>
</tr>
<tr>
<td></td>
<td>Finish mill top face</td>
<td>M8</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rough mill all around</td>
<td>M5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Finish mill all around</td>
<td>M6</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mill slots (4)</td>
<td>M9</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mill bottom of slots</td>
<td>M10</td>
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</tbody>
</table>
## OPERATION SHEET

### PART TYPE 4

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<th>Operation Description</th>
<th>Tool</th>
<th>Time (mins)</th>
<th>Machines</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Drill 10 dia. holes (12)</td>
<td>D1</td>
<td>9</td>
<td>1 or 2 or 5</td>
</tr>
<tr>
<td></td>
<td>Enlarge holes to 20 dia. (12)</td>
<td>D3</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ream 20 dia. holes (12)</td>
<td>R3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>02</td>
<td>Rough mill end face</td>
<td>M3</td>
<td>17</td>
<td>3 or 4</td>
</tr>
<tr>
<td></td>
<td>Finish mill end face</td>
<td>M4</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rough bore dia. $\varnothing_3$</td>
<td>B5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Finish bore dia. $\varnothing_3$</td>
<td>B6</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rough bore dia. $\varnothing_4$</td>
<td>B3</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Finish bore dia. $\varnothing_4$</td>
<td>B4</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Drill 12 dia. holes (4)</td>
<td>D4</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ream 12 dia. holes (4)</td>
<td>R4</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tap 12 dia. holes (4)</td>
<td>T1</td>
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</tbody>
</table>

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# OPERATION SHEET

## PART TYPE 5

<table>
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<tr>
<th>Opn</th>
<th>Operation Description</th>
<th>Tool</th>
<th>Time (mins)</th>
<th>Machines</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Rough mill top face</td>
<td>M5</td>
<td>36</td>
<td>1or2or5</td>
</tr>
<tr>
<td></td>
<td>Finish mill top face</td>
<td>M6</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Drill 5 dia. holes (24)</td>
<td>D5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ream 5 dia. holes (24)</td>
<td>R5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tap 5 dia. holes (24)</td>
<td>T2</td>
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</table>
## OPERATION SHEET

**PART TYPE 6**

<table>
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<tr>
<th>Opn</th>
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<th>Tool</th>
<th>Time (mins)</th>
<th>Machines</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Rough mill bottom face</td>
<td>M7</td>
<td>8</td>
<td>1 or 2 or 5</td>
</tr>
<tr>
<td></td>
<td>Finish mill bottom face</td>
<td>M8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>02</td>
<td>Rough mill top face</td>
<td>M7</td>
<td>14</td>
<td>1 or 2 or 5</td>
</tr>
<tr>
<td></td>
<td>Finish mill top face</td>
<td>M8</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Drill 10 dia. holes (7)</td>
<td>D1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Enlarge holes to 20 dia. (7)</td>
<td>D3</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ream 20 dia. holes (7)</td>
<td>R3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>03</td>
<td>Rough mill inner profile</td>
<td>M9</td>
<td>21</td>
<td>4</td>
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<tr>
<td></td>
<td>Finish mill inner profile</td>
<td>M11</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Rough bore 3 holes of ( \phi_1 )</td>
<td>B1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Finish bore 3 holes of ( \phi_2 )</td>
<td>B2</td>
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</tr>
<tr>
<td></td>
<td>Rough bore 1 hole of ( \phi_3 )</td>
<td>B5</td>
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</tr>
<tr>
<td></td>
<td>Finish bore 1 hole of ( \phi_3 )</td>
<td>B6</td>
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</tbody>
</table>

![Diagram of part type 6](image)
APPENDIX-G

FIXTURE TYPE AND CUTTING TOOLS INFORMATION
### FIXTURE TYPE DETAILS

<table>
<thead>
<tr>
<th>Part type</th>
<th>Opn</th>
<th>Fixture</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>01</td>
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<tr>
<td></td>
<td>02</td>
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</tr>
<tr>
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<td>03</td>
<td>1</td>
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<td>4</td>
<td>01</td>
<td>4</td>
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<td>02</td>
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<td>5</td>
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<tr>
<td>6</td>
<td>01</td>
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<td>26</td>
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<td>29</td>
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</tr>
<tr>
<td>30</td>
<td>T2</td>
<td>Tap 5 mm dia.</td>
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</tbody>
</table>
VITA AUCTORIS

1960 Born in Madras, India on the 28th of June.

1976 Completed high school education from Don Bosco Matriculation School, Madras, India, securing first division.

1977 Completed pre-university course from Loyola College, Madras, India, securing first division.

1982 Graduated from University of Madras, India with a Bachelor of Engineering (Honors) Degree in Production Engineering, securing first division with distinction.

1987 Currently a candidate for the M. A. Sc. Degree in Industrial Engineering at the University of Windsor, Windsor, Canada.