



Evaluation of scheduling rules under different part allocations in a physical FMS model
by H S Umesh

A thesis submitted In partial Fulfillment of the requirements for the degree of Master of Science in
Industrial and Management Engineering
Montana State University
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Abstract:

This research covered. the use of a physical simulator to evaluate various work scheduling rule sets under two different part allocations in a flexible manufacturing system (FMS). The physical model consisted of one Automatic Storage and Retrieval System (AS/RS), two Automatic Guided Vehicle Systems (AGVS) and an AS/RS cart, three identical machine centers, and a robotic cell. The system was capable of manufacturing four different part families, initially classified by Group Technology. Each part family had three identical parts. The AS/RS had three identical parallel storages, each with a capacity of four parts.

The parts were processed, both at the robotic cell and the machine center or only at the machine center, depending on the part family. Each scheduling rule set was a combination of four scheduling rules. The four scheduling rules were used for the following purposes: (a) to select a raw material from the AS/RS, (b) to select a part from the buffer of the robotic cell, (c) to select a machine at the robotic cell, and (d) to select one of the identical machine centers. Each of the scheduling rule sets was evaluated for the following performance criteria: system effectivity, production output, manufacturing throughput time, part traveling time, and work-in-process inventory. A total of fifty four simulation runs was conducted for each of the two different part allocations. Each simulation run was conducted for a period of one hour.

The simulation results indicated that there was no major difference in the results obtained under the two different part allocations. No single scheduling rule set could satisfy all the performance criteria requirements. However, the SPT/FMFS/SPT/WINQ rule set performed better in the overall performance.

Physical simulation provided the unique opportunity for building the hardware interface (between the physical model and the computer) and for writing the software to control the model which was found to be a very rewarding experience and is therefore highly recommended.

**EVALUATION OF SCHEDULING RULES
UNDER DIFFERENT PART ALLOCATIONS
IN A PHYSICAL FMS MODEL**

by

H. S. Umesh

**A thesis submitted in partial fulfillment
of the requirements for the degree**

of

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in

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APPROVAL

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This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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To my loving parents

VITA

Umesh H.S. was born to Seetharam Rao H.M. and Saraswathi H.S. on April 6th 1964, in Bangalore, India. He did his entire schooling at India, from Bangalore. In 1981, he completed his Pre-University schooling from National College and joined University Visveswaraya College of Engineering to pursue his Bachelor of Science degree in Electrical Engineering. He completed his Bachelor's degree in 1986. In 1987, he commenced his higher studies in United States of America, leading to the degree of Master of Science in Industrial and Management Engineering from Montana State University, Bozeman, Montana.

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ABSTRACT

This research covered the use of a physical simulator to evaluate various work scheduling rule sets under two different part allocations in a flexible manufacturing system (FMS). The physical model consisted of one Automatic Storage and Retrieval System (AS/RS), two Automatic Guided Vehicle Systems (AGVS) and an AS/RS cart, three identical machine centers, and a robotic cell. The system was capable of manufacturing four different part families, initially classified by Group Technology. Each part family had three identical parts. The AS/RS had three identical parallel storages, each with a capacity of four parts.

The parts were processed, both at the robotic cell and the machine center or only at the machine center, depending on the part family. Each scheduling rule set was a combination of four scheduling rules. The four scheduling rules were used for the following purposes: (a) to select a raw material from the AS/RS, (b) to select a part from the buffer of the robotic cell, (c) to select a machine at the robotic cell, and (d) to select one of the identical machine centers. Each of the scheduling rule sets was evaluated for the following performance criteria: system effectivity, production output, manufacturing throughput time, part traveling time, and work-in-process inventory. A total of fifty four simulation runs was conducted for each of the two different part allocations. Each simulation run was conducted for a period of one hour.

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INTRODUCTION

In the design and control of industrial facilities, designers are faced with complex structural and operational aspects of facility components as well as their integration into a unified production system. Traditionally, in the academic environment, the complexities have been analyzed using abstract, analytic and/or digital simulation models. Physical simulators have added a new dimension to the field of simulation. Physical simulators are miniature prototype models of real-world situations (e.g. an assembly line, or an automated storage and retrieval warehouse) with many of their essential features and complexities. Under the control of a mini-or-micro-computer, these models mimic the operation of the full scale system undergoing design.

In this research, Fischertechnik components were used to build the physical simulation model of a flexible manufacturing system consisting of a robotic cell, machine centers, AS/RS, and transporters (AS/RS cart and AGVS's). These Fischertechnik components have been used in many university CAD/CAM and robotic laboratories because of their versatility, precision,

and general compatibility with other electrical components. There are more than 400, different, miniaturized parts, such as motors, photocells, conveyer belts, etc.

Basically, the sequence of operation of the parts was dependent on the part family. There were four different part families, with three parts in each part family. Part families 1 and 3 were processed both at the robotic cell and the machine center, whereas, part families 2 and 4 were processed only at the machine center. The parts were initially stored in the AS/RS, and, after each processing, were transported back to the AS/RS. The transportation of the parts was carried out on miniature trains which were the only non Fischertechnik components used in the simulation. These miniature trains were used to simulate the AS/RS cart and the AGVS's.

Different combinations of scheduling rules were evaluated in the physical model. Specific scheduling rules were used for machine center selection, part selection at the AS/RS, and part selection at the robotic cell.

The scheduling rules were evaluated for the following performance criteria: system effectivity, average throughput time, production output, work-in-process inventory, and part traveling time in the robotic cell.

The entire system was interfaced with and controlled by a Z-158 micro computer. A program was written in interpretive BASIC to control the operations of the system.

The primary objective of this research was to determine the most effective combination of scheduling rule for the physical model using the above mentioned performance criteria.

REVIEW OF RECENT LITERATURE

Physical Simulation

Though analytical and/or digital simulation models are useful in gaining qualitative and quantitative understanding of the probable operations of systems, they do not provide adequate opportunities to develop experience with the hardware aspects of the systems. A visual demonstration with actually "moving" components may be useful in studying the intricacies of the design by non-experts, while also reassuring the designer himself, that the operation and control plan is working according to the intended design. Furthermore, these models aid in the material flow and space interactions under various control schemes. Physical simulation requires software development to control the model. Much of this software is transferable to the actual system which is to be controlled [7].

Physical simulation in education has received a great deal of interest in the last few years. It has been used in numerous universities, and is beginning to be used in many more universities. The construction of a physical model to conduct simulations can suggest improvements in design of a manufacturing system by

viewing the spatial relationships among machines, transfer mechanisms, and material handling equipment. Physical simulation can identify opportunities for better flow and sequencing alternatives.

Conventional systems analysis techniques such as dynamic programming, queuing theory, and digital simulation have been very useful to solve various production problems in manufacturing systems. Digital simulation techniques such as SIMAN, SIMSCRIPT, GASP, SLAM, and GPSS have significantly advanced the art of systems analysis. Nof, Deisenroth, and Meir, however wrote that digital simulation tends to be abstract and, is, therefore, difficult to convey results obtained from digital simulation and to convince decision-makers that a proposed design concept is going to achieve their expected goals [1].

The advantages of physical simulation can be outlined as follows [1]:

1. Reducing risks of high initial investment cost for constructing advanced manufacturing systems;
2. Developing control software programs to maximize system effectivity;
3. Considering various design configurations by arranging and rearranging the physical model in order to establish the best configuration for an

application;

4. Convincing a decision maker visually that his/her decision algorithms are effective through visual performance evaluation.

Flexible Manufacturing System [6]

In recent years, manufacturing industries in the United States and other industrialized countries such as Japan, West Germany, Great Britain, etc. have accelerated the move toward automated manufacturing. Factors that have motivated this move include the need to increase productivity, high cost of labor, and the desire for closer management control over production operations. Manufacturers have embarked on a program of replacing the older versions with more modern versions and more highly automated systems of machines. Use of industrial robots, computer-numerical-control machining centers, computer-controlled material handling and storage systems, and computer-aided inspection techniques (such as machine vision) are examples of opportunities for the integration of advanced computer control systems into manufacturing operations. The implementation of many of these systems also reflects a relatively new philosophy: flexible automation or flexible manufacturing systems. The first proposals were made in the mid-1960's (Williamson, 1967; Brosheer,

1968), but recent years have produced a growth in the number of such systems. It is estimated that in excess of a hundred systems has been installed till now.

A precise definition of a flexible manufacturing system (FMS) has yet to be written. However, FMS's represent an emerging, new manufacturing technology - an increasingly serious intent to improve factories. One working definition is: FMS is a production system for small batches where manual, semi-automatic, or fully automatic workstations are directly serviced by an automated material handling system, with capability of simultaneously processing a variety of different part types at workstations and controlled by a centralized computer [6]. The earlier proposed FMS's contained a number of common features, most of which have been retained in recent installations and are as follows [8]:

1. Interlinked, NC work-stations operating on a limited range or family of workpieces in a manner similar to group technology of conventional machines. In some early proposals the machines were of modular construction, but, in most recent systems, general purpose NC machines have been used.
2. Automatic transportation, loading and unloading of workpieces.
3. Workpieces mounted on pallets for transportation,

partly to overcome the unloading/reloading problems at each workstation.

4. Centralized NC or direct numerical control (DNC), together with overall computer control of the system.
5. Operation for significant periods of time with little or no operator intervention.

FMS's are capable of producing a variety of different parts or assemblies on the same basic setup without significant time losses due to changeovers. The variety of parts that can be handled by these system is limited. The parts must have similar geometries (same basic sizes and shapes). Group technology principles are used to design the systems and organize the work that goes through them. FMS's typically consist of a series of workstations that are connected by a materials-handling and storage system. A central computer is used to control the various activities that occur in the system, routing the various parts to the appropriate stations, and controlling the programmed operations at the different stations. With flexible automation, different products can be made at the same time on the manufacturing system [13]. This feature allows a level of versatility not available with any other manufacturing system. This means that products can be produced on a FMS in batches by type if necessary , or

several different product types can be mixed for processing by the system. The computational power of the control computer makes this versatility possible.

The gradual evolution of a totally automated flexible system can be traced as follows:

FMS is much more than a mere 'buzz word'. Far-sighted managers have recognized the FMS as an attractive vehicle to introduce radical change into manufacturing. With increasing disadvantage, much of today's manufacturing industry finds itself in the vast middle ground where it cannot effectively use the transfer line and dedicated manufacturing techniques which are so well suited to high-volume, high-variety work [14]. On the other hand, stand-alone or NC machines traditionally used on middle-to-low-volume, high-variety situations are also experiencing disadvantages. Recent experience indicates capital equipment utilization as low as 20%, high manning levels, and WIP costs which have tripled in the past 10 years, and excessive costs associated with trying to control traditional shop floor operations. FMS technology has evolved over the last two decades to effectively meet the requirements of this middle ground - the vital, mid-volume/mid-variety world of manufacturing. In most firms this middle ground is a cause of unprofitability. FMS's have the potential to

help change all that. The FMS brings flexibility - flexibility to make the part when it is required by the market and not when the production schedule allows flexibility to redesign products to meet changes in the market requirements without making further investment [6]. It provides the route to far greater machine utilization. The products produced are more consistent and improved in quality. Fitting and assembly time are reduced. Scrap levels are cut. The FMS is a major stepping stone to unmanned manufacture.

The full FMS installation is one in which a process is put under total computer control to produce a variety of products within the group technology and to a pre-determined schedule. In the longer term, the FMS is a natural partner for computer-aided-design and computer-aided-manufacturing programs which can bring the product from design to physical being by the most cost effective route. In one sense it could be argued that a transfer line is a type of FMS installation. However such argument would ignore the one crucial and fundamental factor that separates an FMS from any other kind of manufacturing unit: its ability to accept components at random. In other words, a FMS can be designed, if required, to process any product in a family in the cell in any order. A FMS is much more the group technology with a computer. The function of the

computer is to identify the needs of the FMS unit, and to meet those needs by allocating resources in the form of tooling, fixtures, materials handling systems, and inspection modules.

Flexible Manufacturing Cells

Flexible manufacturing cells are basically a development of the machine center concept, but with the addition of a pallet pool or magazine. The aim is to machine the workpiece at one setting. In general, this type of machine can be operated unmanned for long periods of time with the palletized workpieces transferred automatically between the magazine and the machine.

Flexible Transfer Lines

Flexible transfer lines consist of a number of NC or head-changeable machine tools combined by automatic material transfer systems. The systems produce a family of parts but without flexible routing of parts. Consequently, the family of parts being processed will be quite small in number and similar to one another, as the overall flexibility of the system is too low for a larger variety of parts to be accommodated.

Robots

Industrial Robots: [4]. Industrial robots are essentially programmable handling devices, which have

three or more degrees of freedom and which can be fitted with tooling for a variety of tasks like welding, spray painting, etc. A typical robot has three degrees of freedom for the arm, based upon cylindrical, spherical, or other coordinate axes system. Onto this may be superimposed 2 or 3 degrees of freedom for wrist motion. A gripper or hand is required to handle the workpieces. A wide variety of grippers have been devised for holding various items. In adapting a robot to a new task, the grippers must be redesigned to accommodate the new item to be handled, as well as programming the robot for the new task.

A common task for robots is machine loading. However, most applications of robots have been dedicated to large-scale production tasks rather than small-to-medium-batch production, due to their inherent programming capability. Loss of application of flexibility is explained partly because the grippers and tooling must be adapted to a new task, even though reprogramming the robot may be straight forward. The use of robots in group technology cells is attractive, provided that adaptation of tooling and grippers to new parts in a batch production environment can be made efficient. Since group technology cells are designed to process families of less than total parts similar parts, the design of universal grippers is advantageous.

Industrial robots spot-weld automobile bodies, feed material into punch-presses, spray-paint, perform dangerous activities like cleaning up nuclear waste, underwater cleanup, etc. Principal manufacturers of industrial robots include Unimation and Cincinnati Milacron in the US, ASEA in Sweden, and several companies in Japan. Unfortunately, the price range of most industrial robots - \$35,000 to \$120,000 - hinders robot experimentation in schools. Use of less-expensive educational robots is then mandated.

Educational Robots (Microbots' TeachMover robot)

[5]. Since 1979, Microbot, Inc. has been developing low-cost manipulating robots for education and industrial evaluation. This robot called the TeachMover is a self-contained system, including the manipulator, on-board computer, hand-held teach control, host computer interface, and the control language. By using this robot, one would not have to undertake a major development effort to gain a sound working knowledge of robot operation. This discussion of the TeachMover is necessary, since this was the robot used for simulation purposes in the FMS system. The TeachMover robot arm is a microprocessor-controlled, six-jointed mechanical arm designed to provide an unusual combination of dexterity and low cost. The TeachMover can be used in either of

the following modes:

1. Teach control mode, in which the hand-held teach control can be used to teach, edit, and run a variety of manipulation programs.
2. Serial interface mode, in which the TeachMover can be controlled by a host computer or a computer terminal via one of the two built-in RS-232 asynchronous serial communication lines.

Six stepper motors with gear assemblies are mounted on the body and control each of the six joints. In other words, the robot has six degrees of freedom with a direct cable-drive system. The TeachMover arm has a lifting capacity of one pound when fully extended and a resolution of 0.011 inches. The maximum speed is 2 to 7 inches per second, depending upon the weight of the object. It has a maximum reach of 17.5 inches and a maximum gripping force of 3 lb. The controller is a 6502A microprocessor with 4K bytes of EPROM and 1K byte of RAM located in the base of the unit. The control is open loop. The baud rate is switch-selectable between 110 to 9600. The teach control is a 14-key, 13-function keyboard with 5 output and 7 input bits under computer control. The power requirement is 12 volts, 4.5 amp. All members are connected to each other by means of shafts which pass through bushings mounted on the members.

Group Technology [8]

The concept of Group Technology utilized in a flexible automated system is very important and needs special emphasis. The basic concept is relatively simple: identify and bring together related or similar parts and processes, to take advantage of the similarities which exist during all stages of design and manufacture [8]. In traditional batch production industry, the parts are separated by the operations needed to make them, and then tediously carried from one department to the next. In a survey of one plant for example, parts made a 4-mile circuit through their various processing steps. Long and uncertain throughput times are the source of the delivery problem which so often exists for customers of the small-batch manufacturer. These results in stocks being kept to ensure against such non-delivery. Pre-production tasks such as detail design, process planning and NC programming are time consuming and involve the management and retrieval of large amounts of data and documents. Such information handling is well suited to processing by computer, but the development of efficient computer-based procedures may require a rationalized approach, in particular in a high-variety manufacturing situation. Application of the the basic principles of

group technology can lead to a rationalization of NC programming and work planning, which may facilitate the development of efficient computer-aided systems.

Scheduling Principles [9]

Scheduling principles are delineated with the purpose of accumulating many possible scheduling objectives. The most important objective is to increase the utilization of the resources available, i.e., to reduce the resource idle time. For a set of finite tasks, resource utilization is inversely proportional to the time required to accomplish all tasks. This time is referred to as the "makespan" or "maximum flow time" of a schedule. In a finite problem, resource utilization is improved by scheduling the set of tasks so as to reduce the makespan.

Another important scheduling objective is to reduce work-in-process (WIP), to reduce the average number of tasks waiting in a queue while the resources are busy with other tasks.

One final objective for scheduling is to reduce some function of tardiness. In many situations, some or all of the tasks, have due dates and a penalty is incurred if a task is finished after that date. One can reduce the maximum tardiness, or one can reduce the

number of tardy tasks.

A number of scheduling algorithms or rules has been investigated in order to achieve the objectives described above. When reviewing dispatching rules, different authors have evaluated different priority dispatching rules for the job shop for various shop sizes, structures, and performance criteria [9]. In most cases, SPT rule was one of the best performers [10].

The literature available in the field of physical simulation as applicable to FMS is very limited. This is mainly due to the fact that the field of physical simulation itself is in the development stage, and so is FMS. Not much of research has been done in these fields leading to limited literature availability.

METHOD OF ANALYSIS

Description of the Physical Layout

The physical layout of the plant can be broadly classified into five major categories: the AS/RS, the robotic cell, the part loader, the machine centers, and the transporters, each described below. The entire plant layout is as shown in Figure 1.

AS/RS

There are three storages in the AS/RS (Automated Storage/Retrieval System) of the physical plant. Each storage stores raw material, work-in-process inventory (WIP), and finished parts. In other words, there is no separate storage area for the part as it passes from the raw-material stage to finished part stage. The same storage area which is allocated to the part as a raw material is retained for its WIP and finished part storage. It serves the purpose of saving space on the layout for three different storage areas and is in line with the basic principle of simulation where the finished part is fed back as raw material to prevent the feeding of new parts into the system. Each storage has a capacity of four parts. The entire AS/RS has basically the same type of construction. Motors and

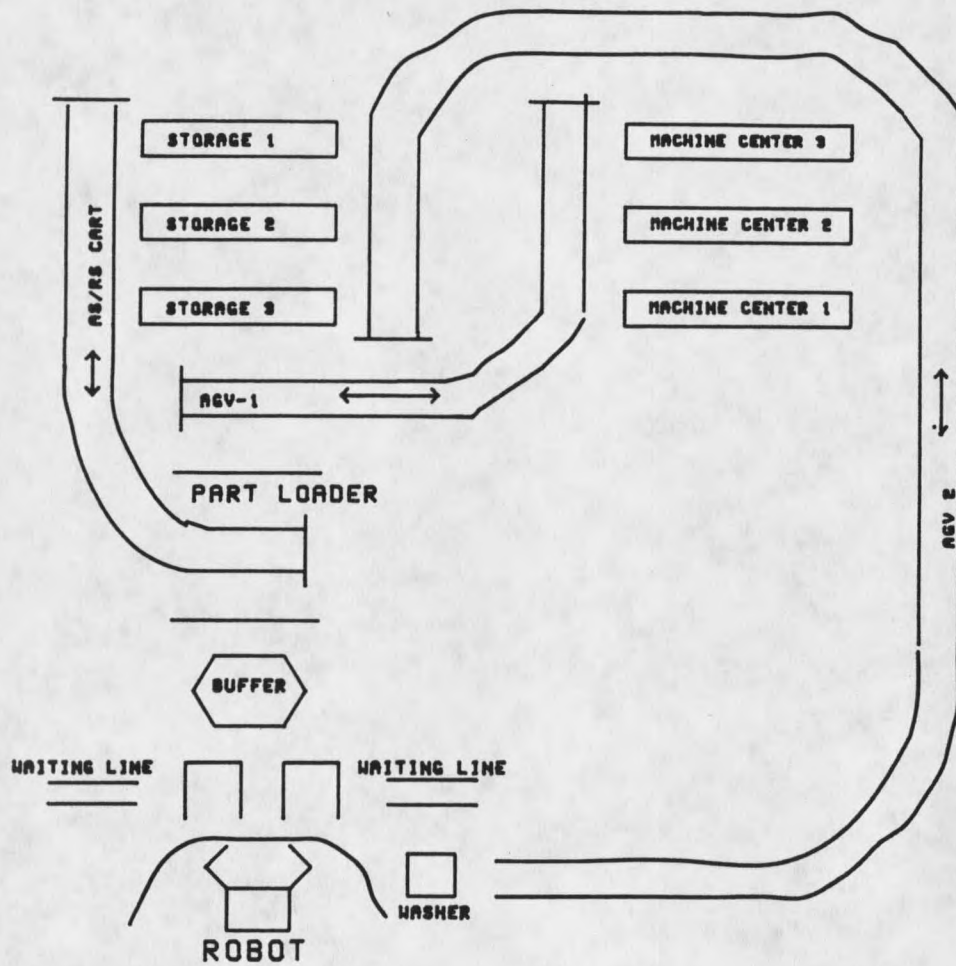


Figure 1

Physical Plant Layout

electro-magnets are used for the part movement in the AS/RS. The parts are stored on a horizontal, flat platform constructed using of building blocks. Parts must either be lifted up and placed on the AS/RS cart which carries the part for processing to a specific machine, or be lifted from the AGV-2 (which carries the part back after its processing) and placed back at its original storage area. The part, itself, is a rectangular plastic piece with a strip of steel attached on top of it. One bi-directional motor with an electro-magnet attached at its bottom is used to lift and place the part. The motor provides the vertical movement and the electro-magnet is energized or de-energized depending on whether the part has to be lifted or lowered. The horizontal movement along the AS/RS rack is provided by another bi-directional motor. A press-switch attached to the horizontal motor is used as a sensor to stop the part at any desired storage location. A vertical piece of building block is built above each storage location along the rack so that the press-switch can determine the exact location of each part. Both the bi-directional motors have gear boxes attached to them.

Part-Loader

The purpose of part loader in the layout is to serve as a junction for the parts being moved either to

the machine center or to the robotic cell. The parts have a fixed processing sequence, depending on which they can be processed either at the machine-center or at the robotic cell. The part is transported by the AS/RS cart from the AS/RS to the part-loader from where the part can be dispatched to the appropriate machine. The part is moved from the AS/RS cart to a turn-table if the part has to be processed at the robotic cell, or it is moved to AGV-1 if it has to be processed at the machine-center. Transportation of the part is effected by a unit similar to the one described earlier in the AS/RS section: one bi-directional motor with an electromagnet attached at its bottom to produce the vertical movement, and one bi-directional motor to create horizontal movement with a press-switch attached to sense positional problems.

Machine Centers

The cell layout also consists of three identical machine centers. The machines are represented by three large stationary motors. These machines represent drilling machines with automatic retooling capability. The machine center itself consists of a long horizontal platform with a railing track above the platform. The part is delivered to the machine center by bi-directional AGV-1. A bi-directional motor moving along

the railing track pushes the part from top of AGV-1 onto the horizontal platform and moves it along the platform to where the machine is located. A building block is located by the side of the machine. A press-switch attached to the bi-directional motor can sense the location of the motor as soon as it touches the block placed by the side of the machine and the part can thereby be placed exactly in front of the machine. After the part is machined (which is simulated by turning on the machine motor) it is pushed on top of AGV-2 by the bi-directional motor. No waiting line in front of the machine center existed. The part is delivered to the machine-center from the part-loader by AGV-1 and after being processed is moved back to AS/RS by AGV-2. Since the machines are identical, any part can be processed on any of the machines.

Robotic - Cell

The robotic cell consists of a TeachMover robot, a turn-table (a rotating hexagon) which serves as a buffer, two lathes (represented by two large stationary motors), and a washer (represented by a square box). The lathes and the washer have individual waiting lines. A small horizontal platform is built in front of each of the lathes, so that the part can be placed in front of them. The robot is used to transport the part to the lathes and the washer. The input point to the robotic

cell is the turn-table and after the part is processed, it is carried back on AGV-2 to the AS/RS. The lathes can be turned on or off by means of a switch located behind them and is turned on or off by the robot.

Transporters

Parts are transported from AS/RS to the part-loader by the AS/RS cart represented by a miniature train. Transportation of parts from the part loader to the machine center is handled by AGV-1, which is represented by another toy train. AGV-2 is used to transport the finished part from either the machine center or the robotic cell to the AS/RS. This is also simulated by another miniature train. All the miniature trains have a thin flat plate attached on top of them in order to carry the parts. The movement of the train is possible by: electrifying the tracks to run the trains and de-electrifying the tracks to stop them. A very important concept is, how the transporters are stopped at desired locations. This is made possible by the usage of photo-sensors with small light bulbs in front of them. The toy trains are stopped as soon as the light beam across the photo-sensor is cut or interrupted by the train. The actual construction and the working of the photo-cells is explained in detail later.

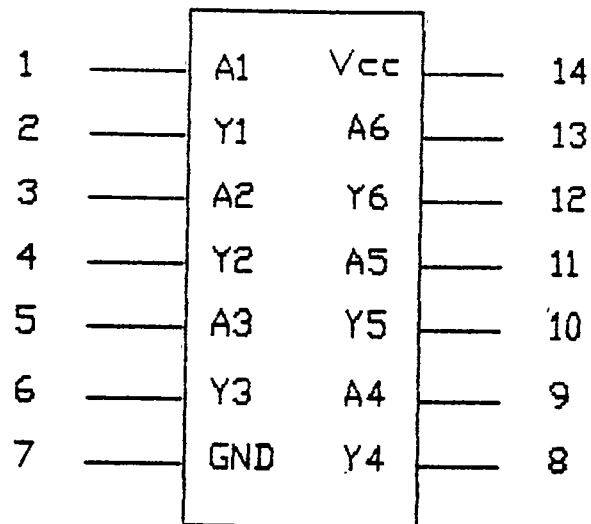
Description of Electric-Circuits

Three different type of electric circuits are built to operate the various Fischertechnik components on the physical plant layout. One of them is to operate the motors, one to operate the trains and another one to monitor the photo-cells. Each of these are described in detail in the following section.

The power requirement of all the Fischertechnik components is 5V, 0.25 MA. However the miniature trains (which were not Fischertechnik) have a power requirement of 16.5V, 0.75A. Therefore, different power supplies have been used. Even though only one power source could have been used to support all the Fischertechnik components, two different sources have been employed to avoid fluctuations in power. One of the sources supports the photo-cell circuit and the press-switches while the other source powers all the motor circuits, the electro-magnets and the light bulbs. The third source is used to power the train-circuit.

Motor Circuit

The circuit built to operate the motor is as shown in Figure 4. The PIA from the computer is connected to a relay input through an inverter. The pinout for the relay and the inverter chip is shown in Figures 2 and 3, respectively. The output of the relay is connected

**Figure 2****7406 Invertor Pin Diagram**

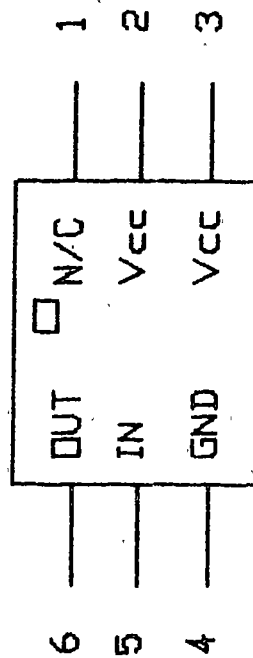


Figure 3
8619 Relay Pin Diagram

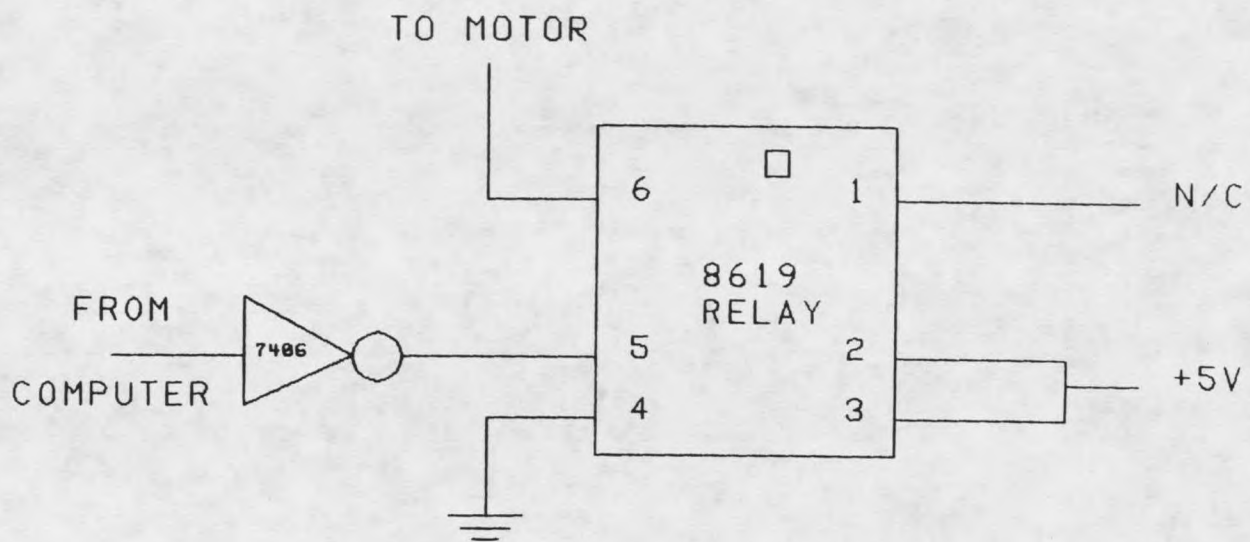


Figure 4
Motor Circuit

to the motor. All the Fischertechnik motors are bi-directional. If the motor is used as a unidirectional motor, the other end of the motor is held at +5V. If it is run as a bi-directional motor, both ends of the motor are connected to the output of two different relays. When a "1" is output from the computer, it was converted to a "0" by the inverter and fed to the relay which flips and holds one end of the motor at ground. Since the other end of the motor is held at +5V (in case of unidirectional), the motor is turned 'on'. By feeding a "0", both ends of the motor are held at +5V which locks the motor or turns it 'off'. In other words, a "1" from the computer switched the unidirectional motor 'on' and a "0" switches the motor 'off'. In case of a bi-directional motor which is connected to two relays (R1 and R2), feeding a "1" to R1 and "0" to R2 from the computer drives the motor in one direction while a "0" to R1 and "1" to R2 drives the motor in the opposite direction. The bi-directional motor is switched 'off' by feeding a "0" to both the relays.

Photo-Cell Circuit

The photo-cell circuit is as shown in Figure 6. One end of the photo-cell is grounded while the other end is connected to the positive input of a quad comparator, LM 339. The pin-out of LM 339 is as shown in Figure 5. The negative input of the comparator is

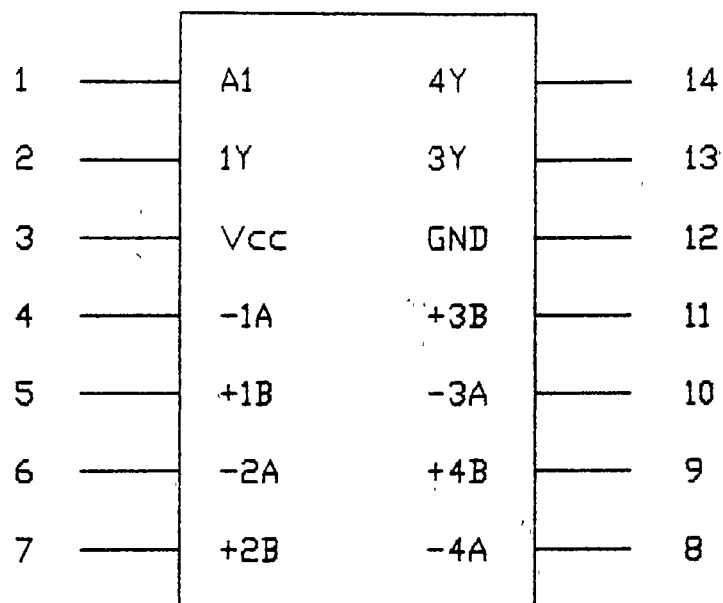
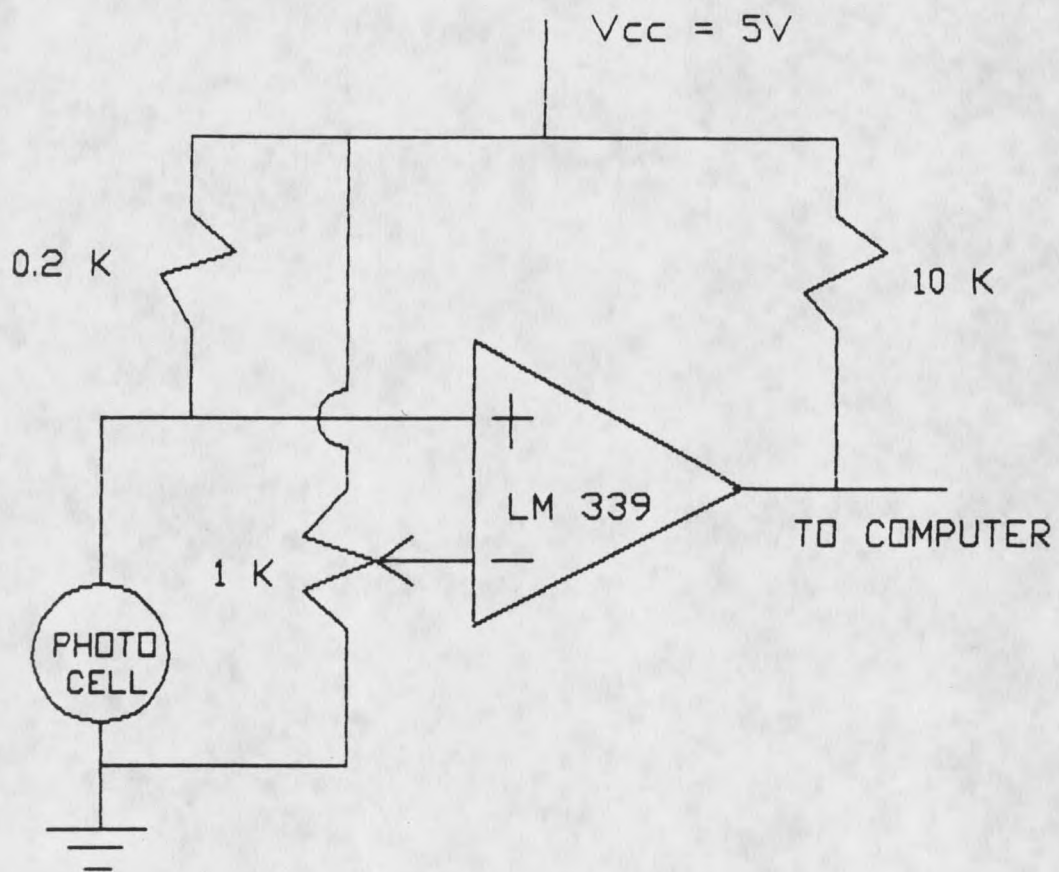


Figure 5
LM 339 Pin Diagram

**Figure 6****Photo cell circuit**

connected to a potentiometer. The positive input is also biased through a 200-ohm resistor. The output of the comparator (biased by a 10k-ohm resistor) is connected to the PIA of the computer. As long as there is a light beam on the photo-cell (cast by the light bulb in front of the photo-cell), the photo resistance of the cell is high and a voltage of around 2.5V is fed to the positive input of the comparator. The comparator outputs either 5V or 0V even though the voltage levels are different. If the voltage is more than 1.8V, the comparator outputs 5V, and so, in the above case it outputs 5V which the PIA in the computer senses as a '1'. In order to prevent this, the potentiometer at the negative input is adjusted to feed 2.5V, so that the comparator after comparing the two inputs, which is 2.5V with opposite polarity, outputs a '0'. When the light beam across the photo-cell is obstructed, the photo-resistance decreases, and therefore a voltage of around 4.5V is fed to the positive input of the comparator. Since the difference in the voltages is more than 1.8V, the comparator outputs 5V, which the PIA senses as a '1'. The basic principle in operating the photo-cell therefore is that it outputs a '1' when it is blocked and outputs a '0' when the light beam is cast on it.

Train Circuit

The basic circuit for operating the trains is the

same as that of a bi-directional motor, except that one of the supplies to the relay is a 16.5V power source. The circuit diagram for the Train circuit is as shown in Figure 7.

Miscellaneous Components:

Electro-Magnet: One end of the electro-magnet is connected to the computer while the other end is grounded.

Press Switch: The press-switch has three connections to be made. One of them is directly to the computer while the other two connections are to the power and ground, respectively. The pin-out of the press-switch is as shown in Figure 8.

Toggle Switch: One of the components that is not connected to the computer, but is used to turn motors 'on' and 'off' is a toggle switch whose pin-out is as shown in Figure 9.

Parallel Interface Adapter (PIA)

The PIA used for parallel communication is the 37 pin, Metrabyte chip 8255A. The most important feature of 8255A is its ability in being programmed, apart from being able to provide an Input/Output(I/O) interface with parallel communication. The following are the features of 8255A:

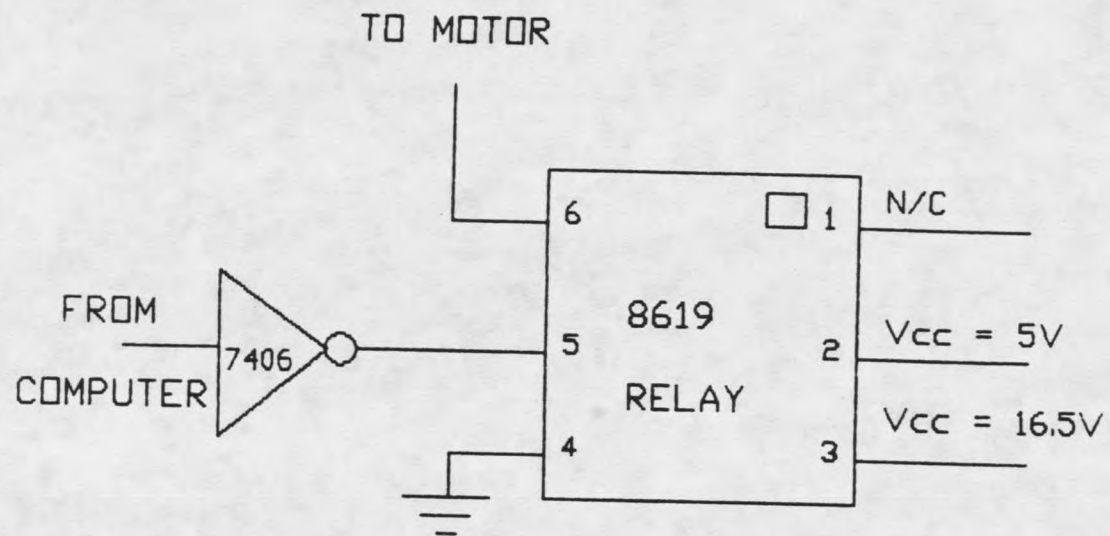


Figure 7
Train circuit

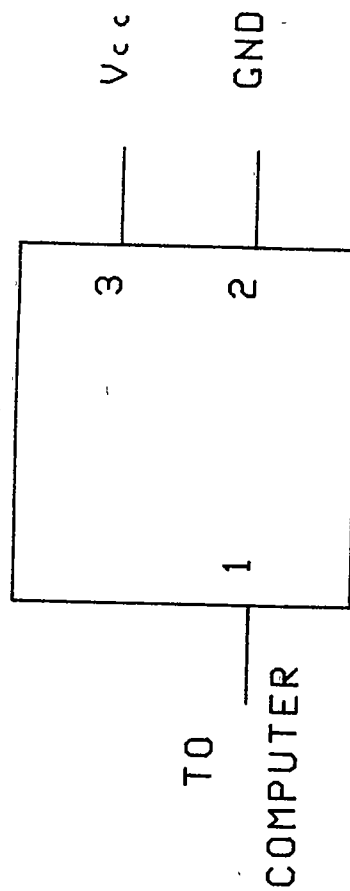


Figure 8
Press Switch Pin Out

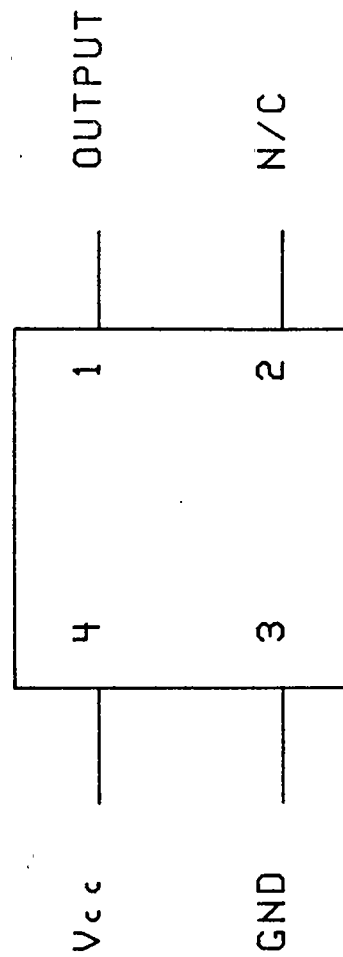


Figure 9
Toggle Switch Pin Out

- . 24 TTL/DTL digital I/O lines
- . 12V / 5V power from IBM PC/XT
- . Unidirectional, bi-directional strobed I/O
- . Interrupt Handling
- . Direct interface to wide range of peripherals
- . Plugs into IBM PC/XT/AT bus
- . Handshaking

Its applications include the following:

- . Contact closure monitoring
- . Printer/Plotter interface
- . Digital I/O control
- . Magnetic tape units
- . Card reader interface

The purpose of the PIA in this research is to provide digital I/O control. The following is the functional description of the 8255A:

24 digital I/O lines are provided through an 8255-5 Programmable Peripheral Interface (PPI) IC and consists of three ports, an 8-bit A port, an 8-bit B port, and an 8-bit C port. The C port may also be used as two half ports of 4 bits, C upper (C4-7) and C lower (C0-3). Each of the ports and half ports may be configured as an input or output by control software according to the contents of a write only control register in the PPI. The A,B and C ports may be read as

well as written to. Unidirectional and bi-directional strobed I/O is also possible. The block diagram of 8255A is as shown in Figure 10.

Connector Pin Assignments

All digital I/O is through a standard 37 pin D type standard male connector that projects through the rear panel of the computer. The connector pin assignments are as shown in Figure 11.

Base Address Switch

The 8255-5 PPI uses I/O address locations which are fully decoded within I/O the address space of the IBM PC. The base address was set by an 8 position DIP switch which is as shown in Figure 12 and can in theory be placed anywhere in I/O address space, but base address below FF hex (255 decimal) should be avoided as this address range was used by the internal I/O of the computer. The 200-3FF hex (decimal 512-1023) address range provides extensive unused areas of I/O space. The address map for the PPI registers is as follows:

Base Address

A Port	+0	Read/Write
B Port	+1	Read/Write
C Port	+2	Read/Write
Control	+3	Write only

Switch Settings

The switch setting is as shown in Figure 12.

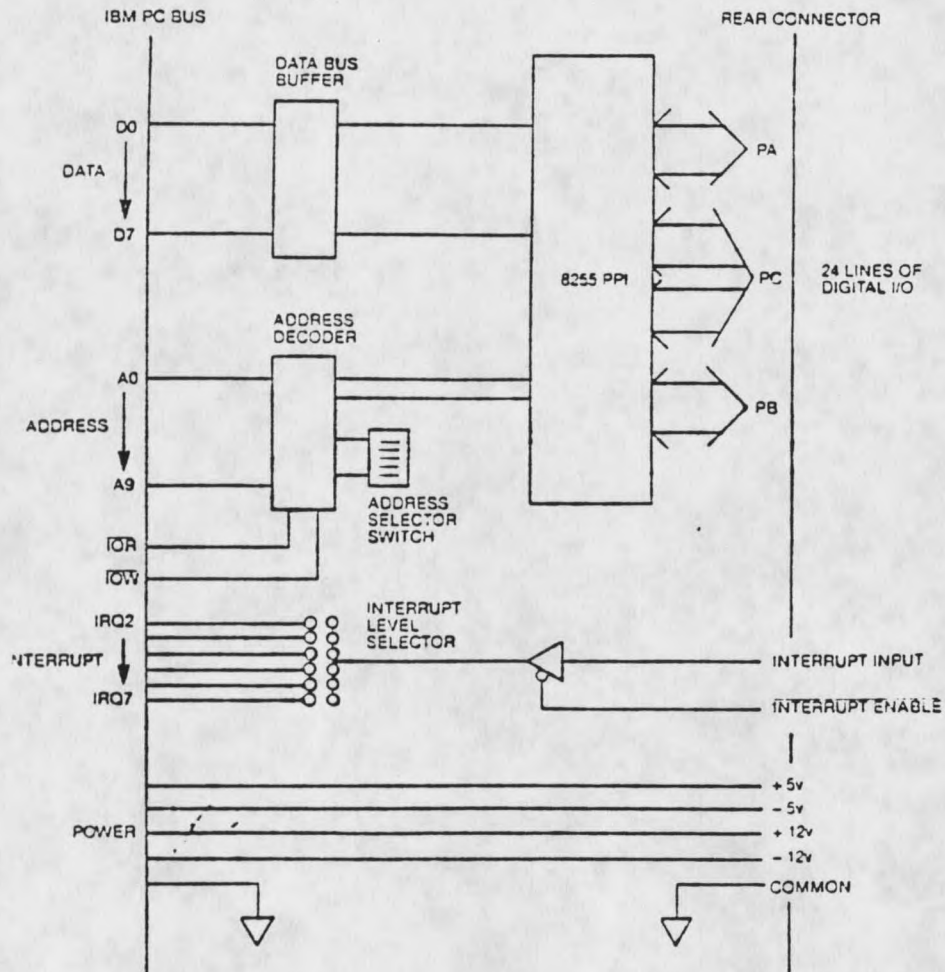


Figure 10
PIA Block Diagram

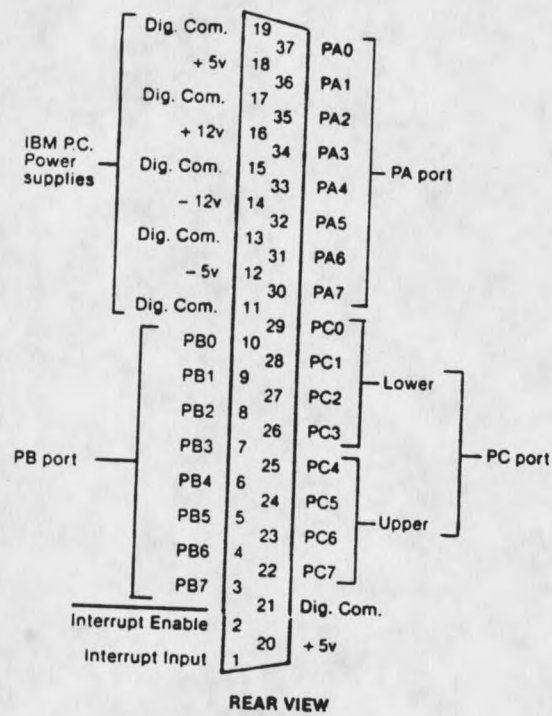


Figure 11
PIA Connector Pin Assignments

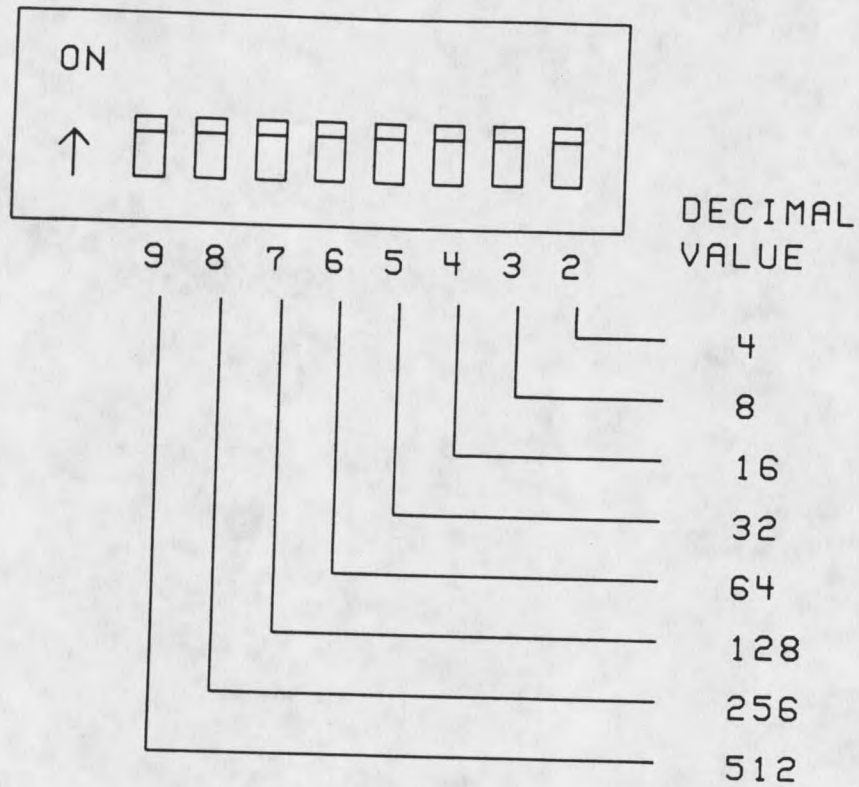


Figure 12
DIP Switch Settings

These switches have decimal values in the 'off, position. In the 'on' position, the decimal value is zero. The S1 switch setting as shown in Figure 12 is for 300 hex or 768 decimal.

Programming

The PIA can be programmed either in BASIC or ASSEMBLY language and is quite simple. The PPI should be configured in the initialization section of the program by writing to the control register. On power up all ports are configured as inputs. A wide variety of configurations are possible by writing the appropriate control word to the control register.

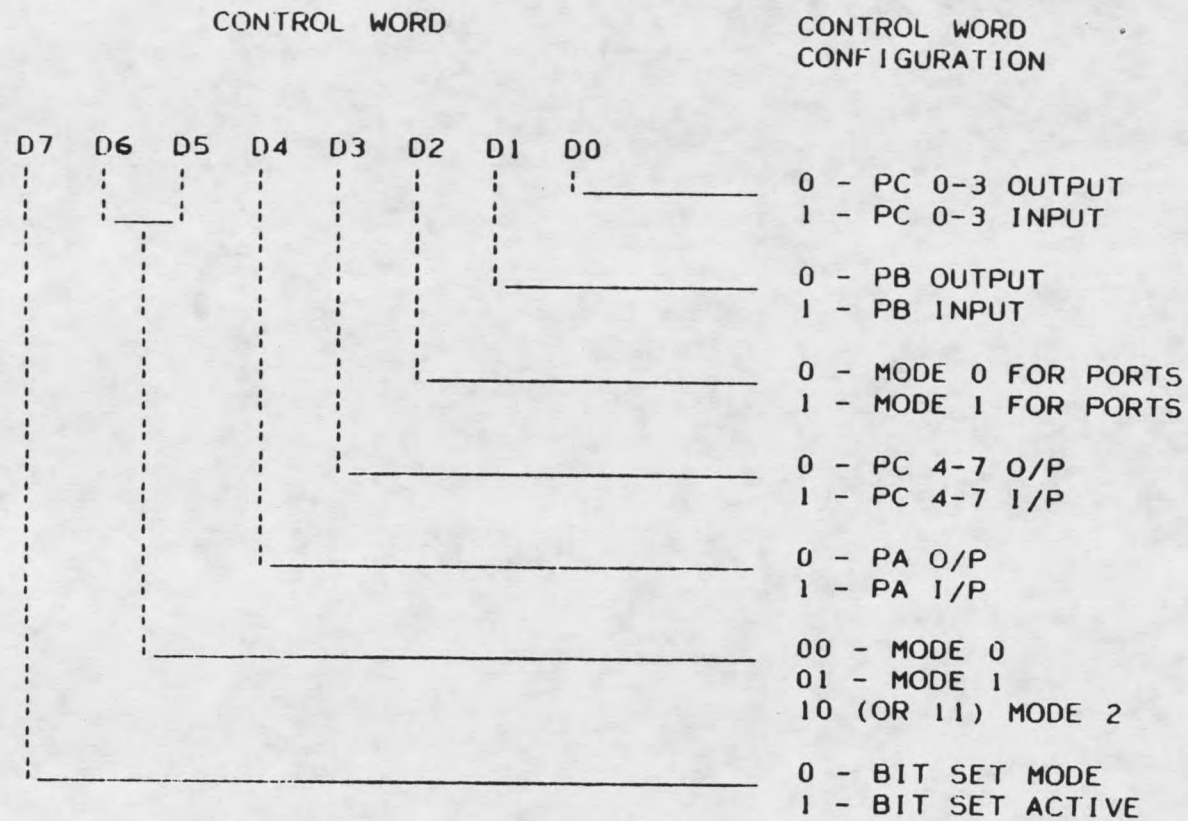
The control word configuration is as shown in Figure 13. Note that D7 must be high (=1) to set the configuration of the ports. The operating mode used in this research is always Mode 0 - that is, all ports are I/O ports. Therefore, pins D5-6 is 00 and pin D2 is 0. The rest of the pins were configured, depending on whether the ports were used as input or output.

Interface

The interface between the computer and the physical model is through the PIA board. The number of inputs (photocells, press-switches) and outputs (motors, magnets and trains) on the physical plant that needed to be interfaced is 62. Each PIA can provide 24 I/O lines

Control Word Configuration

Figure 13



through its three ports. Therefore, three PIA boards are used for interfacing. The default address on the PIA as sent from the manufacturer is H300 for all boards. Therefore the address of two of the three PIA boards have to be changed to avoid the clash which would have resulted, if the the same address was used. Using the DIP switch on the PIA, the base address of the two PIA boards has been changed to H200 and H380, respectively. The three PIA boards are then connected through a ribbon cable to a large circuit board, where the three ports from each of the PIA boards are isolated.

Six circuit boards have been built with the motor circuit, photocell circuit and the train circuit soldered on them. Three boards are dedicated to the motor circuit, two to the photocell circuit and one to the train circuit. Each of the boards have several circuits on them. The PIA port connections from the large circuit board is then connected to one of the circuits on the six circuit boards. The connections to any component on the physical plant is through one of the circuits of the six circuit boards. Thus the route of electrical connection from the physical plant to the computer is:

Physical plant ----> circuit on one of the six circuit boards ----> port pins on the large circuit board ---->

PIA in the computer.

Part Allocation

The physical simulation is conducted with four different part families being taken into account. Each of the scheduling rule set is repeated for two different part allocation methods (i.e. storage of parts at the AS/RS) at the AS/RS. Each part family has three identical parts. Therefore the total number of parts in the system is twelve. The first storage allocation of parts in the AS/RS is in a random fashion. The second allocation has a set pattern and is as shown in Figure 14.

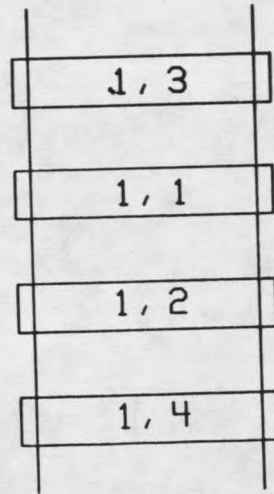
Processing Sequence

The processing sequence of part family 1 and part family 3 is as shown in Figure 15 and Figure 16, respectively, whereas the processing sequence of part family 2 and part family 4 is as shown in Figure 17 and Figure 18, respectively.

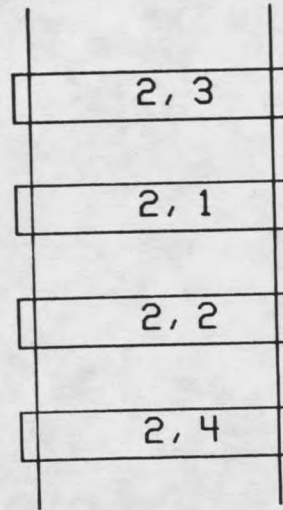
All the parts start their processing sequence from the AS/RS and after each operation, are returned back to the AS/RS to be stored as a in-process inventory or finished product, depending on its sequence. At the end of the simulation, if any product cannot be finished, it is counted as a in-process inventory. The finished part



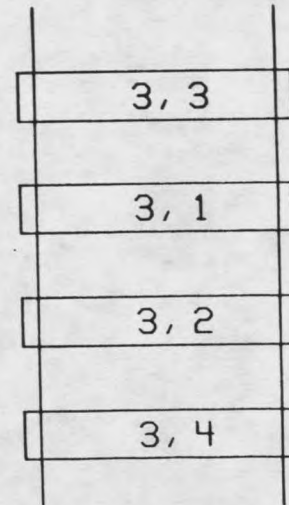
STORAGE 1



STORAGE 2



STORAGE 3



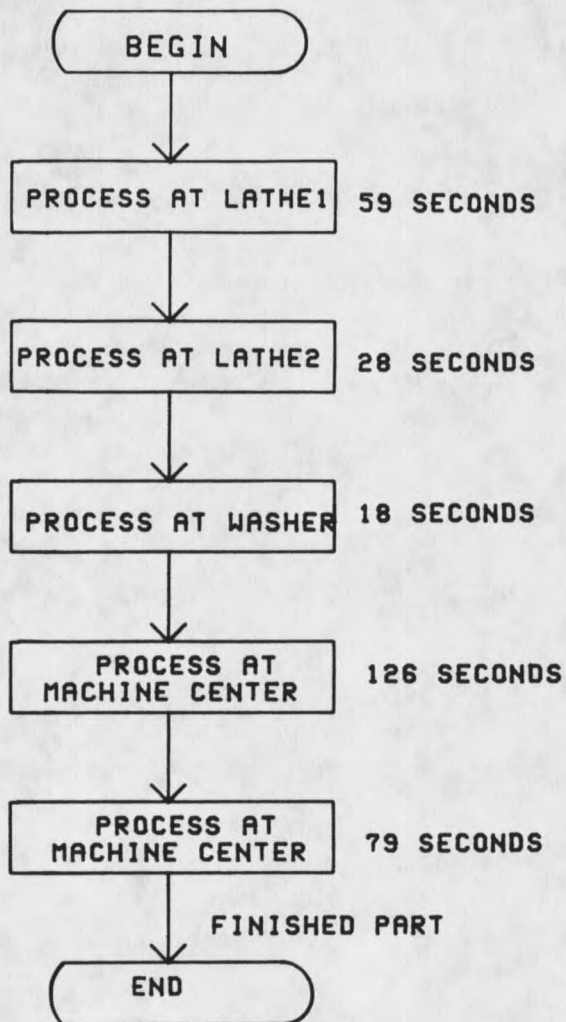


Figure 15
Processing Sequence of Part Family 1

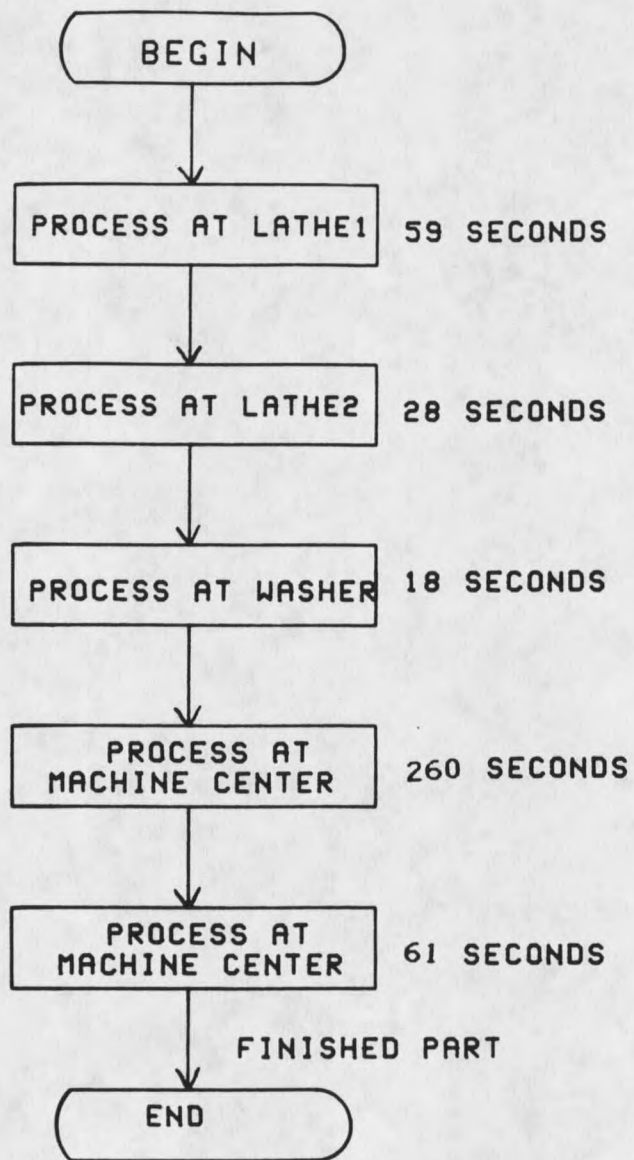


Figure 16
Processing Sequence of Part Family 3

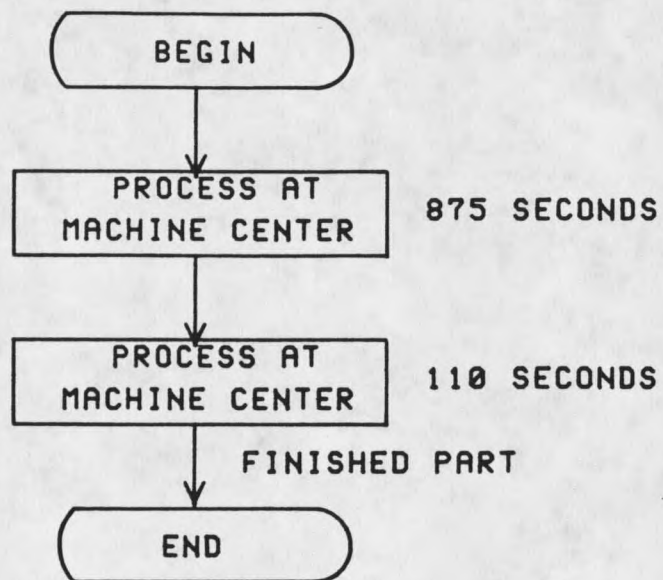


Figure 17
Processing Sequence of Part Family 4

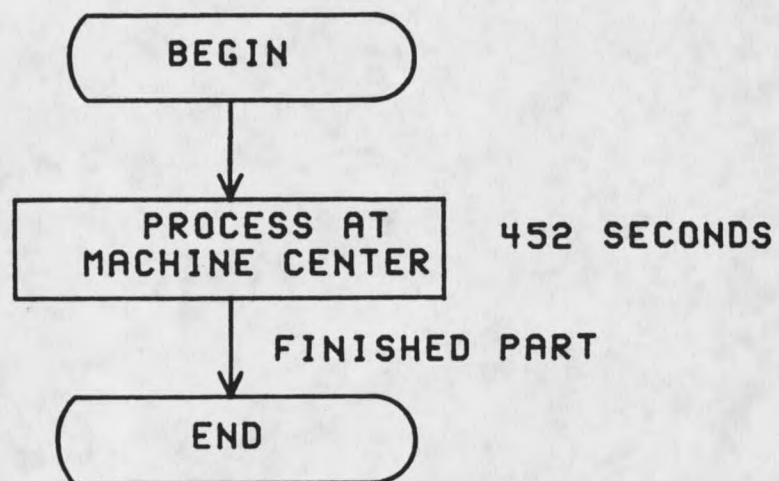


Figure 18

Processing Sequence of Part Family 2

is considered as a raw material to avoid the feeding in of new parts in the middle of the simulation.

The parts follow a fixed sequence at the robotic cell in that they were sequentially processed in the following order:

Lathe 1 ----> Lathe 2 ----> washer

Even though part families 1, 3 and 4 are processed twice at the machine center, they are not required to be operated by any particular machine at the machine center, since all the machines are identical.

Unscaled Processing Time

Table 1. Unscaled part processing time

PART FAMILY	ROBOTIC CELL			MACHINE CENTER		TOTAL
	Lathe	Lathe	Washer	machine	machine	
	1	2		1	2	
	mins.	mins.	mins.	mins.	mins.	mins.
1	10.9	5.1	3.2	47.8	11.2	78.2
2	-	-	-	82.8	-	82.8
3	10.9	5.1	3.2	23.0	14.4	56.6
4	-	-	-	160.4	20.2	180.6

Time Scaling

The actual process times, shown in Table 1 are scaled down by a factor of 11 to suit the requirements of physical simulation. The scaling factor of 11 is

chosen because this model is quite similar in system configuration and part family description to the model simulated by Choi and Malstrom [7], who chose a scaling factor of 11 for their model. The authors considered two factors to determine the scaling factor. The first factor is the time required to fetch a part from a storage area, defined as the fetch time. Since the speed of the AS/RS cart is constant, the fetch time varies with the distance that the cart travels. The second factor is the route time. Route time is defined as the time required for a part selected by the AS/RS cart to be routed to a machine center or the buffer of the robotic cell. Route time varies with the distance of each machine center from the the AS/RS system. After a part is retrieved by the AS/RS, the part's destination in the system has to be determined. This destination is dependent on both the part type being retrieved and the scheduling rule set being used. The obtained scaling factors ranged from 11.60 to 12.21. Simple decision rule sets required less time for the control computer to execute. Therefore they generally had higher scaling factors, while the opposite was true for the more complex rule sets. Thus a compromise has been made, and a scaling factor of 11 is chosen. The time scaled processing times are as shown in Table 2.

Table 2. Scaled part processing time

PART FAMILY	ROBOTIC CELL			MACHINE CENTER		TOTAL
	Lathe	Lathe	Washer	machine	machine	
	1 secs	2 secs	secs	1 secs	2 secs	
1	59	28	18	260	61	426
2	-	-	-	452	-	452
3	59	28	18	126	79	310
4	-	-	-	875	110	985

It has to be mentioned here that the processing times of the different part families are constant times and does not follow any statistical distribution. Although the process times are scaled, the time required for transferring the parts (like in AS/RS, Robot, loader system at the machine center and overhead crane system at AS/RS and part loader) is indigenous to the physical simulator. The velocities of the overhead cranes are basically inflexible and are determined by the rated voltage of 6V. The robot velocity also has to be restrained to obtain better repeatability and precision. The train velocities are limited by the requirement to handle the curves of the track and to stop at exact locations consistently. The average speed of the trains is determined to be 1.2'/sec and the average velocity of the overhead cranes is 0.9'/sec. The average speed of the robot is 3"/sec.

Part Selection

A combination of scheduling principles have been tested out on the physical layout to find out the most optimal scheduling combination. The scheduling rules can be used on either a single processor (machine) or multiple processors (machines) and a variety of performance criteria such as mean flow time, mean lateness, mean tardiness, etc. can be evaluated.

Various scheduling principles are used for the different areas in the layout for part selection and machine selection and they can be broadly classified into four major part selection categories: part selection at (1) AS/RS, (2) buffer at robotic cell, (3) waiting line at robotic cell and (4) machine center selection. The different scheduling rules used at each of the different areas is briefly described below:

Part Selection at AS/RS

First Storage First Served (FCFS): Storage area 1 receives the highest priority with priority decreasing for subsequent storage areas. Storage area 3 receives the least priority.

Shortest Processing Time (SPT): A storage area whose part has the shortest processing time is selected.

Longest Processing Time (LPT): A storage area whose part has the longest processing time is selected.

Machine-Center Selection

Most Work Remaining (MWKR): A machine center which has the most work remaining is selected.

Least Work Remaining (LWKR): This is an opposite case of MWKR in that the machine center which has the least work remaining is chosen.

First Machine First Selected (FMFS): The closest machine center has the highest priority and the farthest machine has the lowest priority.

Part Selection at Buffer of Robotic Cell

First Come First Selected (FCFS): The part which arrives first at the buffer receives the highest priority with decreasing priority for subsequent parts such that the last part receives the least priority.

Shortest Processing Time (SPT): A storage area whose part has the shortest processing time is selected.

Longest Processing Time (LPT): A storage area whose part has the longest processing time is selected.

Machine Selection Robotic Cell

Work In Next Queue (WINQ): A machine (at the robotic cell) that has the least work in queue in terms of processing time is chosen.

Number In Next Queue (NINQ): A machine which has the lowest number of parts in queue is chosen.

Simulation Runs

The number of simulation runs is calculated by taking a combination of all the scheduling rules used. Here is all possible combinations for the simulation.

- . Number of part selection rules at AS/RS = 3
- . Number of part selection rules at robotic cell
buffer = 3
- . Number of part selection rules at
waiting line of robotic cell = 2
- . Number of machine center selection rules = 3

Therefore total number of simulation runs = $54 (3*3*2*3)$

Since the simulation is repeated for two different part configurations, the total number of simulation runs is $108 (54*2)$.

Each of the simulation runs is conducted for a time period of 60 minutes or 1 hour.

Performance Criteria

Each of the scheduling rule combinations have been evaluated for the following performance criteria:

System Effectivity

System effectivity is defined as the ratio of total actual processing times of all physical components (AS/RS cart, AGVS, robot, overhead crane at AS/RS and

part loader, part loader at machine center and machining time at machine center and robotic cell) to the total available production time.

Production Output

Production output is the total number of finished parts produced at the end of each simulation run.

Average Throughput Time

The average throughput time is determined by dividing the sum (completion time - arrival time) of all the finished parts, by the total number of finished parts.

Work - In - Process Inventory

Work-in-process inventory is the total number of semi-finished parts (at the AS/RS, buffer and waiting line of robotic cell) in the entire system at the end of the simulation run.

Part Traveling Time

Part traveling time is defined as the sum of the total operation time of: overhead crane system at the AS/RS + loader system at the machine center + run time of AS/RS cart, AGV 1, AGV 2.

Control Software

The Zenith - 158 PC is re-equipped with three Metrabyte parallel interface adapter boards. The

software to control the physical model has been written in interpretive BASIC. The complete program source code, called the 'FMS simulation' is listed in Appendix B. The structure of the program can be identified by the following components:

Initialization and Declarations

This section initializes the ports of the PIA, sets up communication lines with the robot and opens necessary files.

Subroutines

All the different tasks in the model, like retrieval of a part, placing of a part, routing of a part, etc., were built in as subroutines in the program. This procedure was adopted since the same task is performed repeatedly in the program. The coding in the form of subroutines helped to reduce the length of the program to a great extent.

Main Body

This section was used to control or call the different subroutines, depending on the scheduling rule set being used. Also, the processing times of the parts was controlled by this section of the program.

Robot Subroutine

This subroutine was written in ARMBASIC (which is BASIC compatible) and was called on each time the robot

had to be operated. Even though all the components in the model were controlled through a parallel interface, the robot control was through an RS-232 serial interface. The subroutine written was such that the computer dumps all the coordinates into the memory of the robot and is then free to perform any other operation. This means that while the robot is being operated by the program from its own memory, some other task is being performed by the computer leading to a pseudo multi-tasking. This operation greatly increases the efficiency of the total operation.

DATA COLLECTION AND ANALYSIS

Data Collection

The performance data were collected for each of the different performance criteria under two different part allocations. The statistical analysis of the data was not performed since it was considered beyond the scope of this research and therefore the data was strictly collected to calculate the different performance criteria values under each scheduling rule combination. At the beginning of each simulation run, the real time clock of the computer was set to zero. All simulation data were measured in model time. The model time was an adjusted time reduced by a time scaling factor of 11. The 108 simulation runs was conducted for two different part allocations (at the AS/RS) and eleven different scheduling rules. Each simulation run was a combination of four scheduling rules - part selection at the AS/RS, part selection at the buffer of the robotic cell, part selection at the waiting line of the robotic cell and machine center selection. Each of these scheduling rule combination was evaluated for five different performance

criteria: system effectivity, average throughput time, production output, part traveling time and work-in-process inventory. The performance of each scheduling rule combination for random part allocation and fixed part allocation is as shown in Table 3 and Table 4, respectively.

The total actual processing times of the transporters and machines for each simulation run were needed to calculate the system effectivity. This time was kept track by the real time clock of the computer. To calculate the average throughput time, an array was opened for each part. This array kept track of the arrival time of the part and the completion time of the part. The difference between the two times gave the throughput time for that individual part. A counter in the program recorded the total number of parts produced during each simulation run. There was an array to keep track of the processing sequence of the part. This array was used to calculate the total number of work-in-process inventories at the end of the simulation run. To calculate the part traveling time, the time taken by all the transporters, cranes and loaders was clocked using the real time clock of the computer and stored into a variable.

Table 3. Performance of scheduling rule combination for random part allocation.

Scheduling rule combination	A	B	C (min.)	D (min.)	E
FSFS/FMFS/FCFS/NINQ	.4484	14	17.3	4.46	3
FSFS/FMFS/FCFS/WINQ	.4486	16	16.4	4.50	5
FSFS/FMFS/SPT/NINQ	.4698	14	16.1	4.50	4
FSFS/FMFS/SPT/WINQ	.4641	14	15.8	4.15	4
FSFS/FMFS/LPT/NINQ	.4126	15	17.4	4.33	7
FSFS/FMFS/LPT/WINQ	.4144	16	16.2	4.23	7
FSFS/LWKR/FCFS/NINQ	.4188	16	15.4	3.96	7
FSFS/LWKR/FCFS/WINQ	.4189	17	15.1	4.06	4
FSFS/LWKR/SPT/NINQ	.4032	17	15.0	4.35	4
FSFS/LWKR/SPT/WINQ	.4042	17	15.2	4.08	5
FSFS/LWKR/LPT/NINQ	.4036	18	14.9	4.08	6
FSFS/LWKR/LPT/WINQ	.4000	18	14.9	4.13	7
FSFS/MWKR/FCFS/NINQ	.3968	15	16.6	4.26	6
FSFS/MWKR/FCFS/WINQ	.4012	16	15.8	4.16	2
FSFS/MWKR/SPT/NINQ	.4042	16	15.6	4.18	2
FSFS/MWKR/SPT/WINQ	.3942	17	15.6	4.16	3
FSFS/MWKR/LPT/NINQ	.3982	16	16.6	4.23	3
FSFS/MWKR/LPT/WINQ	.3998	16	16.2	4.16	4
SPT/FMFS/FCFS/NINQ	.4344	18	14.8	4.01	7
SPT/FMFS/FCFS/WINQ	.4300	18	14.6	4.20	6
SPT/FMFS/SPT/NINQ	.4144	18	14.2	4.08	1
SPT/FMFS/SPT/WINQ	.4186	19	14.1	3.98	4
SPT/FMFS/LPT/NINQ	.3988	18	14.8	4.03	6
SPT/FMFS/LPT/WINQ	.3891	18	14.4	4.06	6
SPT/LWKR/FCFS/NINQ	.4133	18	15.0	4.13	6
SPT/LWKR/FCFS/WINQ	.4188	18	14.9	4.03	6
SPT/LWKR/SPT/NINQ	.4112	18	14.6	4.36	6
SPT/LWKR/SPT/WINQ	.4188	17	15.0	4.43	7
SPT/LWKR/LPT/NINQ	.3911	18	14.9	4.23	6
SPT/LWKR/LPT/WINQ	.3878	17	15.2	4.03	5
SPT/MWKR/FCFS/NINQ	.3700	17	15.1	4.48	9
SPT/MWKR/FCFS/WINQ	.3755	17	15.4	4.53	6
SPT/MWKR/SPT/NINQ	.3788	17	15.0	4.18	7
SPT/MWKR/SPT/WINQ	.3617	18	15.2	4.23	7
SPT/MWKR/LPT/NINQ	.3436	15	15.7	4.06	1
SPT/MWKR/LPT/WINQ	.3421	17	15.2	4.15	4
LPT/FMFS/FCFS/NINQ	.3443	16	16.0	4.43	5
LPT/FMFS/FCFS/WINQ	.3431	16	16.4	4.33	4
LPT/FMFS/SPT/NINQ	.3776	15	16.8	4.45	6
LPT/FMFS/SPT/WINQ	.3798	17	16.4	4.30	5
LPT/FMFS/LPT/NINQ	.3776	15	17.1	4.51	5
LPT/FMFS/LPT/WINQ	.3800	15	16.9	4.31	4
LPT/LWKR/FCFS/NINQ	.3944	15	16.8	4.11	2
LPT/LWKR/FCFS/WINQ	.4000	16	16.5	4.36	4
LPT/LWKR/SPT/NINQ	.3744	14	17.3	4.48	0
LPT/LWKR/SPT/WINQ	.3885	15	16.9	4.48	4
LPT/LWKR/LPT/NINQ	.3760	14	17.2	4.33	6
LPT/LWKR/LPT/WINQ	.3664	14	17.5	4.35	4
LPT/MWKR/FCFS/NINQ	.3503	16	16.3	4.23	3
LPT/MWKR/FCFS/WINQ	.3672	16	16.5	4.16	4
LPT/MWKR/SPT/NINQ	.3922	15	16.6	4.41	1
LPT/MWKR/SPT/WINQ	.3700	16	16.3	4.51	3
LPT/MWKR/LPT/NINQ	.3311	13	17.5	4.45	3
LPT/MWKR/LPT/WINQ	.3320	16	16.9	4.38	2

* A - system effectivity, B - production output,
 C - average throughput time/part, D - part traveling time,
 E - work - in -process inventory

Table 4. Performance of scheduling rule combination for fixed part allocation.

Scheduling rule combination	A	B	C (min.)	D (min.)	E
FSFS/FMFS/FCFS/NINQ	.4518	15	16.2	4.70	2
FSFS/FMFS/FCFS/WINQ	.4533	14	17.8	4.61	1
FSFS/FMFS/SPT/NINQ	.4300	14	17.7	4.43	4
FSFS/FMFS/SPT/WINQ	.4272	16	16.0	4.53	0
FSFS/FMFS/LPT/NINQ	.4100	14	16.7	4.58	1
FSFS/FMFS/LPT/WINQ	.4132	15	17.6	4.61	1
FSFS/LWKR/FCFS/NINQ	.4022	14	16.4	4.51	5
FSFS/LWKR/FCFS/WINQ	.4033	14	17.0	4.51	6
FSFS/LWKR/SPT/NINQ	.4188	14	16.9	4.48	1
FSFS/LWKR/SPT/WINQ	.4084	14	16.8	4.23	4
FSFS/LWKR/LPT/NINQ	.3994	15	16.5	4.35	2
FSFS/LWKR/LPT/WINQ	.4040	15	16.3	4.41	1
FSFS/MWKR/FCFS/NINQ	.3942	16	16.1	4.35	2
FSFS/MWKR/FCFS/WINQ	.3940	16	16.0	4.15	0
FSFS/MWKR/SPT/NINQ	.3833	16	15.7	4.18	4
FSFS/MWKR/SPT/WINQ	.3800	17	15.1	4.16	3
FSFS/MWKR/LPT/NINQ	.3855	14	16.6	4.06	8
FSFS/MWKR/LPT/WINQ	.3788	13	14.6	4.16	4
SPT/FMFS/FCFS/NINQ	.4001	17	15.0	4.21	3
SPT/FMFS/FCFS/WINQ	.4000	17	15.1	4.25	0
SPT/FMFS/SPT/NINQ	.4217	19	13.5	4.01	7
SPT/FMFS/SPT/WINQ	.4127	19	13.9	3.98	5
SPT/FMFS/LPT/NINQ	.3987	14	16.7	4.25	1
SPT/FMFS/LPT/WINQ	.4041	16	16.1	4.28	2
SPT/LWKR/FCFS/NINQ	.4141	17	15.7	4.13	1
SPT/LWKR/FCFS/WINQ	.4042	17	15.4	4.03	3
SPT/LWKR/SPT/NINQ	.3940	16	16.1	4.16	5
SPT/LWKR/SPT/WINQ	.3900	16	15.8	4.28	3
SPT/LWKR/LPT/NINQ	.3987	16	15.9	4.18	6
SPT/LWKR/LPT/WINQ	.4040	17	15.2	4.08	4
SPT/MWKR/FCFS/NINQ	.3876	17	15.3	4.06	4
SPT/MWKR/FCFS/WINQ	.3880	17	15.4	4.06	2
SPT/MWKR/SPT/NINQ	.3954	16	16.0	4.20	2
SPT/MWKR/SPT/WINQ	.4000	15	16.3	4.21	2
SPT/MWKR/LPT/NINQ	.3535	16	16.1	4.05	1
SPT/MWKR/LPT/WINQ	.3632	15	16.2	4.06	0
LPT/FMFS/FCFS/NINQ	.3444	17	15.2	3.90	8
LPT/FMFS/FCFS/WINQ	.3400	16	15.7	4.01	7
LPT/FMFS/SPT/NINQ	.3567	18	14.8	4.08	5
LPT/FMFS/SPT/WINQ	.3667	18	14.2	4.06	4
LPT/FMFS/LPT/NINQ	.3889	18	14.5	4.31	2
LPT/FMFS/LPT/WINQ	.3445	18	14.4	4.23	1
LPT/LWKR/FCFS/NINQ	.3668	17	15.0	4.20	1
LPT/LWKR/FCFS/WINQ	.3800	16	15.1	4.25	0
LPT/LWKR/SPT/NINQ	.3778	18	14.4	4.20	1
LPT/LWKR/SPT/WINQ	.3800	18	14.7	4.33	2
LPT/LWKR/LPT/NINQ	.3980	17	15.2	4.25	3
LPT/LWKR/LPT/WINQ	.3880	17	15.0	4.08	2
LPT/MWKR/FCFS/NINQ	.3700	16	15.6	4.16	4
LPT/MWKR/FCFS/WINQ	.3788	16	15.8	4.08	3
LPT/MWKR/SPT/NINQ	.3425	15	16.6	4.33	2
LPT/MWKR/SPT/WINQ	.3560	15	15.9	4.31	4
LPT/MWKR/LPT/NINQ	.3721	17	15.4	4.25	3
LPT/MWKR/LPT/WINQ	.3750	17	15.0	4.08	3

* A - system effectivity, B - production output,
 C - average throughput time/part(min.),
 D - part traveling time(min), E - work - in -process inventory

To accommodate the different scheduling rule combinations in the same program a sequential file was opened. By simply changing the data of this sequential file, different set of scheduling rule combinations was obtained. The changing of these data had to be done manually for each scheduling rule combination.

The robot was programmed to perform a specific set of movements using a program written in ARMBASIC and BASIC. The program source code is listed in Appendix A. Program 'Teachrobot' was developed to 'train' the robot manually. Each set of movements was recorded manually through the teach-pendant of the robot and stored as a sequential file on the disk using the 'Teachrobot' program. To run the robot through the computer during the simulation run, another subroutine was used in the main program which read the value of the coordinates from the sequential file and transmitted them back to the robot so that the robot was run in precisely the same order in which it was recorded. Six different sequential files were recorded using the 'Teachrobot' program - one to move a part from the buffer to machine 1, one to move a part from the buffer to the waiting line of machine 1, one to move a part from machine 1 to machine 2, one to move a part from machine 2 to washer, one to place a part from the washer to AGV-2 and one to

move a part from the waiting line of machine 1. The robot was returned back to the home position after each set of movements to reduce the resulting cumulative error.

Analysis Procedure

The relative ranks of all the scheduling rule combinations with respect to the five different performance criteria under random part allocation is as shown in Table 5 and under the fixed part allocation is as shown in Table 6.

Table 7 and Table 8 show the best and the worst scheduling rule combination(s) for each performance criterion under random part allocation and fixed part allocation, respectively.

Part Allocation

The data collected was not subjected to any form of statistical analysis. The difference in the values of the performance criteria in the two different part allocations was due to the fact that the fetch time of the parts at the AS/RS and their storage time was different owing to their different storage allocations. This was the only factor that was distinctly different between the two different part allocations. The rest of the operations remained exactly same in both the allocations.

Table 5. Relative ranking of scheduling rule combinations for random part allocation.

Scheduling rule combination	A	B	C	D	E
FSFS/FMFS/FCFS/NINQ	4	6	24	25	6
FSFS/FMFS/FCFS/WINQ	3	4	17	27	4
FSFS/FMFS/SPT/NINQ	1	6	15	27	5
FSFS/FMFS/SPT/WINQ	2	6	13	10	5
FSFS/FMFS/LPT/NINQ	12	5	25	18	2
FSFS/FMFS/LPT/WINQ	10	4	16	14	2
FSFS/LWKR/FCFS/NINQ	8	4	10	1	2
FSFS/LWKR/FCFS/WINQ	7	3	8	6	5
FCFS/LWKR/SPT/NINQ	16	3	7	4	5
FCFS/LWKR/SPT/WINQ	14	3	9	7	4
FCFS/LWKR/LPT/NINQ	15	2	6	3	3
FCFS/LWKR/LPT/WINQ	18	2	6	9	2
FCFS/MWKR/FCFS/NINQ	22	5	19	15	3
FCFS/MWKR/FCFS/WINQ	17	4	13	11	7
FCFS/MWKR/SPT/NINQ	14	4	11	12	7
FCFS/MWKR/SPT/WINQ	24	3	11	11	6
FCFS/MWKR/LPT/NINQ	21	4	19	14	6
FCFS/MWKR/LPT/WINQ	19	4	16	11	5
SPT/FMFS/FCFS/NINQ	5	2	5	4	2
SPT/FMFS/FCFS/WINQ	6	2	4	13	3
SPT/FMFS/SPT/NINQ	10	2	2	3	8
SPT/FMFS/SPT/WINQ	9	1	1	2	5
SPT/FMFS/LPT/NINQ	20	2	5	5	3
SPT/FMFS/LPT/WINQ	27	2	3	6	3
SPT/LWKR/FCFS/NINQ	11	2	7	9	3
SPT/LWKR/FCFS/WINQ	8	2	6	19	3
SPT/LWKR/SPT/NINQ	13	2	4	26	3
SPT/LWKR/SPT/WINQ	8	3	7	23	2
SPT/LWKR/LPT/NINQ	26	2	6	14	3
SPT/LWKR/LPT/WINQ	29	3	9	5	4
SPT/MWKR/FCFS/NINQ	37	3	8	26	1
SPT/MWKR/FCFS/WINQ	35	3	10	29	3
SPT/MWKR/SPT/NINQ	32	3	7	12	2
SPT/MWKR/SPT/WINQ	40	2	9	14	2
SPT/MWKR/LPT/NINQ	43	5	12	6	8
SPT/MWKR/LPT/WINQ	45	3	9	10	5
LPT/FMFS/FCFS/NINQ	42	4	14	23	4
LPT/FMFS/FCFS/WINQ	44	4	17	18	5
LPT/FMFS/SPT/NINQ	33	5	20	24	3
LPT/FMFS/SPT/WINQ	31	3	17	16	4
LPT/FMFS/LPT/NINQ	33	5	22	28	4
LPT/FMFS/LPT/WINQ	30	5	21	17	5
LPT/LWKR/FCFS/NINQ	23	5	20	8	7
LPT/LWKR/FCFS/WINQ	18	4	18	20	5
LPT/LWKR/SPT/NINQ	36	6	24	26	9
LPT/LWKR/SPT/WINQ	28	5	21	26	5
LPT/LWKR/LPT/NINQ	34	4	23	18	3
LPT/LWKR/LPT/WINQ	39	6	26	19	5
LPT/MWKR/FCFS/NINQ	41	4	16	14	6
LPT/MWKR/FCFS/WINQ	38	4	17	11	5
LPT/MWKR/SPT/NINQ	25	5	19	22	8
LPT/MWKR/SPT/WINQ	37	4	16	28	6
LPT/MWKR/LPT/NINQ	46	7	26	24	6
LPT/MWKR/LPT/WINQ	47	4	21	21	7

* A - system effectivity, B - production output,
C - average throughput time/part, d - Part traveling time,
E - work - in - process inventory

Table 6. Relative ranking of scheduling rule combinations for fixed part allocation.

Scheduling rule combination	A	B	C	D	E
FSFS/FMFS/FCFS/NINQ	2	5	19	28	7
FSFS/FMFS/FCFS/WINQ	1	6	29	26	8
FSFS/FMFS/SPT/NINQ	3	6	28	22	5
FSFS/FMFS/SPT/WINQ	4	4	17	25	9
FSFS/FMFS/LPT/NINQ	10	6	26	27	7
FSFS/FMFS/LPT/WINQ	8	5	27	26	8
FSFS/LWKR/FCFS/NINQ	16	6	21	24	4
FSFS/LWKR/FCFS/WINQ	15	6	27	24	3
FCFS/LWKR/SPT/NINQ	6	6	26	23	8
FCFS/LWKR/SPT/WINQ	11	6	25	15	5
FCFS/LWKR/LPT/NINQ	17	5	22	20	7
FCFS/LWKR/LPT/WINQ	14	5	20	21	8
FCFS/MWKR/FCFS/NINQ	20	4	18	12	7
FCFS/MWKR/FCFS/WINQ	21	4	17	10	9
FCFS/MWKR/SPT/NINQ	27	4	14	12	5
FCFS/MWKR/SPT/WINQ	28	3	9	11	6
FCFS/MWKR/LPT/NINQ	26	6	23	6	1
FCFS/MWKR/LPT/WINQ	29	7	23	11	5
SPT/FMFS/FCFS/NINQ	15	3	8	14	6
SPT/FMFS/FCFS/WINQ	16	3	9	16	9
SPT/FMFS/SPT/NINQ	5	1	1	3	2
SPT/FMFS/SPT/WINQ	9	1	2	2	4
SPT/FMFS/LPT/NINQ	18	6	24	16	8
SPT/FMFS/LPT/WINQ	13	4	18	8	7
SPT/LWKR/FCFS/NINQ	7	3	14	9	8
SPT/LWKR/FCFS/WINQ	12	3	12	4	6
SPT/LWKR/SPT/NINQ	21	4	18	11	4
SPT/LWKR/SPT/WINQ	22	4	14	17	6
SPT/LWKR/LPT/NINQ	18	4	16	12	3
SPT/LWKR/LPT/WINQ	14	3	10	2	5
SPT/MWKR/FCFS/NINQ	24	3	11	6	5
SPT/MWKR/FCFS/WINQ	25	3	12	6	7
SPT/MWKR/SPT/NINQ	19	4	17	13	7
SPT/MWKR/SPT/WINQ	16	5	20	14	7
SPT/MWKR/LPT/NINQ	42	4	18	5	8
SPT/MWKR/LPT/WINQ	36	5	19	6	9
LPT/FMFS/FCFS/NINQ	40	3	10	1	1
LPT/FMFS/FCFS/WINQ	41	4	14	3	2
LPT/FMFS/SPT/NINQ	37	2	7	7	4
LPT/FMFS/SPT/WINQ	35	2	3	6	5
LPT/FMFS/LPT/NINQ	23	2	5	18	7
LPT/FMFS/LPT/WINQ	39	2	4	15	8
LPT/LWKR/FCFS/NINQ	34	3	8	12	8
LPT/LWKR/FCFS/WINQ	28	4	9	16	9
LPT/LWKR/SPT/NINQ	30	2	4	12	8
LPT/LWKR/SPT/WINQ	28	2	6	19	7
LPT/LWKR/LPT/NINQ	18	3	10	16	6
LPT/LWKR/LPT/WINQ	25	3	8	7	7
LPT/MWKR/FCFS/NINQ	33	4	13	11	5
LPT/MWKR/FCFS/WINQ	30	4	15	17	6
LPT/MWKR/SPT/NINQ	43	5	23	19	7
LPT/MWKR/SPT/WINQ	38	5	16	18	5
LPT/MWKR/LPT/NINQ	32	3	12	16	6
LPT/MWKR/LPT/WINQ	31	3	8	7	6

* A - system effectivity, B - production output,
C - average throughput time/part, D - part traveling time,
E - work - in -process inventory

Table 7. Best and worst scheduling rule combinations under random part allocation.

Performance Criterion	Best	Worst
System Effectivity	FSFS/FMFS/SPT/NINQ	LPT/MWKR/LPT/WINQ
Production Output	SPT/FMFS/SPT/WINQ	LPT/MWKR/LPT/NINQ
Average throughput time	SPT/FMFS/SPT/WINQ	LPT/LWKR/LPT/WINQ LPT/MWKR/LPT/NINQ
Part traveling time	FSFS/LWKR/FCFS/NINQ	LPT/FMFS/LPT/NINQ LPT/MWKR/SPT/WINQ
Work-in-process inventory	SPT/MWKR/FCFS/NINQ	LPT/LWKR/SPT/NINQ

Table 8. Best and worst scheduling rule combinations under fixed part allocation.

Performance Criterion	Best	Worst
System Effectivity	FSFS/FMFS/FCFS/WINQ	LPT/MWKR/SPT/NINQ
Production Output	SPT/FMFS/SPT/WINQ SPT/FMFS/SPT/NINQ	FCFS/MWKR/LPT/WINQ
Average throughput time	SPT/FMFS/SPT/WINQ	FSFS/FMFS/FCFS/WINQ
Part traveling time	FSFS/LWKR/FCFS/NINQ	LPT/MWKR/LPT/NINQ LPT/FMFS/LPT/NINQ
Work-in-process inventory	SPT/MWKR/FCFS/NINQ	LPT/LWKR/SPT/NINQ

Part Selection

Even though, none of the scheduling rule combinations dominated all the performance criterion, it was quite evident from Table 7 and Table 8 that the SPT rule performed the best among all the scheduling rules employed, whereas the LPT rule demonstrated the worst performance. The analysis of the results revealed that higher the rate of production, smaller was the average throughput time per part. Since the parts which had the smallest processing time were selected first at the AS/RS and at the buffer of the robotic cell, the total waiting time for the overall processing was reduced significantly. This factor in turn reduced the average throughput time of the parts in the system.

Machine-Center Selection

By selecting the first available machine at the machine center, the utilization of the machines was maximized. The system effectivity was heavily dependent on the machine centers' effectivity. The FMFS rule kept the machines at the machine center occupied for most of the time and therefore increased the actual processing time of the system which resulted in a higher system effectivity.

Part Traveling Time

The part traveling time was affected largely by the

electrical characteristics of the motors in the system and not very much by the scheduling rules themselves. On account of this the part traveling time did not vary significantly. This was evident from the fact that the part traveling time was four minutes in most of the scheduling rule combinations used. Another factor that would most certainly have affected the traveling time was the fact that even though the operation was conducted in parallel, the simulation was conducted without multi-tasking.

Machine Selection at Robotic Cell

The NINQ and WINQ rules applied to select a part from the waiting line of the machines at the robotic cell did not significantly affect any of the performance criteria since there was no waiting part at the second machine at any time and negligibly few parts waiting at the first machine. The second machine at the robotic cell had no parts in the waiting line because the processing time of the parts at the first machine was more (59 seconds) than the processing time of the parts at the second machine (28 seconds). Since the parts had to be processed sequentially at the robotic cell, the second machine was always free to process a part. The robot was in operation and busy transferring the parts through the machines in the cell as a result of which it was not in a position to transfer the part from the

buffer to the waiting line of the first machine. The only time the robot was free to perform this operation (transfer a part from the buffer to the waiting line of machine 1) was when the sequence of operations in the cell was deliberately broken and the robot was forced to move a part from the buffer to the waiting line of machine 1.

In summary it can be stated that the SPT rule at the storage and buffer and the FMFS rule at the machine center performed best in the overall performance.

CONCLUSION AND SUGGESTIONS

An evaluation of various scheduling rule sets under two different part allocations (at the AS/RS) in a physical flexible manufacturing system (FMS) was presented in this research. Fifty four different scheduling rule sets were evaluated for each part allocation. Each of the scheduling rule sets was evaluated for the following five performance criteria: system effectivity, production output, manufacturing throughput time, part traveling time, and work-in-process inventory. The results obtained from this research were the basis for the following conclusions:

There was no major difference in the results obtained under the two different part allocations. This was because, only two factors were different under the two different part allocations - fetch time and traveling time. The rest of the operations remained the same in both the allocations. None of the scheduling rule sets was able to satisfy all the performance criteria. The analysis of the results revealed that higher the rate of production, smaller was the average throughput time per part. Among the individual rules, SPT figured in most of the best scheduling rule sets and

can be classified as the single best scheduling rule. On the contrary, LPT figured in most of the worst scheduling rule sets and can be classified as the single worst scheduling rule. As a scheduling rule set, SPT/FMFS/SPT/WINQ performed better in the overall performance.

Production managers usually have conflicts in making part selections and machine selections. This research would be a substantial effort which would enable managers to actually observe the implementation of scheduling principles physically and make a decision. Finally the use of physical simulation is highly recommended for evaluating scheduling rules since it provides the unique opportunity of developing the hardware and the software for the model which is a very rewarding experience.

The following are the suggestions by the author to improve the quality of this research:

1. A statistical analysis could be performed to validate the data obtained from the simulation. No statistical analysis was conducted as a part of this research, since it was considered to be beyond the scope of this research.
2. Another improvement would be to perform both time scaling as well as physical scaling.

3. The simulation could be repeated by changing the parameters of the model. For example, the processing times could be changed to study the effect on the different performance criteria.
4. The physical simulation results could also be verified by conducting a digital simulation on the physical simulation data.

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APPENDICES

Appendix A

Robot Teach Program

Figure 19. TeachRobot program

```
10 DEFINT A-Z
20 DIM A1(30),A2(30),A3(30),A4(30),A5(30),A6(30)
30 SP=200
40 OPEN "COM1:9600,N,8,1,RS,DS,CS" AS #1
50 FOR J=1 TO 30
60 A1(J)=0:A2(J)=0:A3(J)=0:A4(J)=0:A5(J)=0:A6(J)=0
70 NEXT J
80 OPEN "O",2,"a:TEST1"
90 PRINT#1,"@RESET":INPUT#1,I
100 CLS
110 PRINT "OPERATE THE ROBOT"
120 INPUT"INPUT THE NO OF RECORDINGS";N
130 FOR J=1 TO N
140 PRINT #1, "@SET",SP:INPUT#1,I
150 PRINT #1, "@READ":INPUT#1,I
160 INPUT#1,A1(J),A2(J),A3(J),A4(J),A5(J),A6(J):INPUT#1,I
170 PRINT#2,A1(J),A2(J),A3(J),A4(J),A5(J),A6(J)
180 PRINT A1(J),A2(J),A3(J),A4(J),A5(J),A6(J)
190 PRINT#1,"@RESET":INPUT#1,I
200 NEXT J:CLOSE #2
210 END
```

Appendix B
Control Software

Figure 20. FMS simulation program

```

10 / *****
20 REM PROGRAM TO PERFORM SIMULATION ON THE PHYSICAL MODEL
30 /
40 REM WRITTEN BY: UMESH H.S.
50 /
60 REM DATED: MARCH-20-1989
70 / *****
80 /
90 /
100 /
110 / initialization procedure
120 /
130 /
140 COLOR 15,1,1
150 CLS
160 DIM L(7) : DIM PNT(53)
170 GOSUB 9010
180 OPEN "COM1:9600,N,8,1,RS,DS,CS" AS #1
190 TIME$="0:0:00"
200 ON KEY (6) GOSUB 8910 : KEY (6) ON
210 ON KEY (9) GOSUB 9080 : KEY (9) ON
220 GOSUB 9240
230 OPEN "I", #3, "SEQ"
240 /
250 / *****
260 /
270 /
280 REM : MAIN BODY OF THE PROGRAM
290 /
300 / program to move part #1 on 1st AS/RS to ROBOTIC-CELL
310 /
320 LOCATE 10,15: PRINT " 1st AS/RS HAS BEEN ACTIVATED"
330 INPUT #3,LP1:PRINT LP1:GOSUB 4210
340 INPUT #3,X1:GOSUB 3880
350 GOSUB 9150
360 /
370 / program to move part #2 on 1st AS/RS to ROBOTIC-CELL
380 /
390 /
400 X=115:GOSUB 11760
410 INPUT #3,LP1:GOSUB 4210
420 INPUT #3,X1:GOSUB 3880
430 GOSUB 9150

```

Figure 20 (continued)

```

440 INPUT #3,PL1:GOSUB 4470 : ' Ist AS/RS rack back
450 '
460 ' move part #1 from IInd AS/RS to ROBOTIC-CELL
470 '
480 INPUT #3,LP2:GOSUB 4690
490 INPUT #3,X2:GOSUB 3640
500 GOSUB 9150
510 '
520 ' program to move part #2 on IInd AS/RS to ROBOTIC -CELL
530 '
540 INPUT #3,PL2:GOSUB 4880
550 X=155:GOSUB 11760
560 INPUT #3,LP2: GOSUB 4690
570 INPUT #3,X2: GOSUB 3640
580 GOSUB 9150
590 INPUT #3,PL2:GOSUB 4880: ' IInd AS/RS rack back
600 '
610 ' move part #1 on IIIrd AS/RS to ROBOTIC CELL
620 '
630 INPUT #3,LP3:GOSUB 5100
640 INPUT #3,X3: GOSUB 3360
650 GOSUB 9150
660 '
670 ' program to move part #2 on IIIrd AS/RS to ROBOTIC-CELL
680 '
690 INPUT#3,PL3:GOSUB 5270
700 X=208:GOSUB 11760
710 INPUT #3,LP3:GOSUB 5100
720 INPUT #3,X3:GOSUB 3360
730 GOSUB 9150
740 INPUT #3,PL3:GOSUB 5270 : ' program to move IIIrd AS/RS back
750 '
760 ' program to move part #3 on Ist AS/RS to PART-LOADER
770 '
780 LP1 = 2 :GOSUB 4210
790 X1=5 : GOSUB 3880
800 GOSUB 5390
810 GOSUB 5650
820 GOSUB 5940
830 OUT(&H300),16
840 M1$=TIME$
850 PL1=3:GOSUB 4470 : 'moves Ist AS/RS back
860 '
870 ' program to move part #3 on IInd AS/RS to MCHINE CENTER I
880 '
890 LP2 = 2:GOSUB 4690
900 X2=5:GOSUB 3640

```

Figure 20 (continued)

```
910 GOSUB 5390
920 GOSUB 5650
930 GOSUB 6120
940 OUT(&H300),48
950 M2$=TIME$
960 PL2=3:GOSUB 4880
970 '
980 ' program to move part #3 on IIIRD AS/RS to MACHINE-CENTER III
990 '
1000 LP3=2:GOSUB 5100
1010 X3=5:GOSUB 3360
1020 GOSUB 5390
1030 GOSUB 5650
1040 GOSUB 6300
1050 OUT(&H300),49
1060 M3$=TIME$
1070 PL3=3:GOSUB 5270
1080 STOP
1090 '
1100 'program to process part at robotic cell
1110 '
1120 INPUT #3,PT:GOSUB 8120
1130 ZZ$="1" :GOSUB 8380
1140 L1=TIMER+28
1150 II=2
1160 IF TIMER >=L1 THEN 1170 ELSE 1150
1170 INPUT #3,PT :GOSUB 8120
1180 ZZ$="5" : GOSUB 8380
1190 W1 = TIMER+27
1200 II=2
1210 IF TIMER>=W1 THEN 1220 ELSE 1200
1220 INPUT #3,PT :GOSUB 8120
1230 ZZ$="5" : GOSUB 8380
1240 W1 = TIMER+27
1250 II=2
1260 IF TIMER>=W1 THEN 1270 ELSE 1250
1270 OUT(&H300),33
1280 GOSUB 8120
1290 ZZ$="2" : GOSUB 8380
1300 L2 = TIMER+36
1310 II=1
1320 IF TIMER>=L2 THEN 1330 ELSE 1310
1330 ZZ$="3":GOSUB 8380
1340 WA=TIMER+30
1350 II=2
1360 IF TIMER>=WA THEN 1370 ELSE 1350
1370 ZZ$="4":GOSUB 8380
```

Figure 20 (continued)

```

1380 DR1=TIMER+20
1390 II=1
1400 IF TIMER>=DR1 THEN 1410 ELSE 1390
1410 PP$="1" : GOSUB 7440 : ' program to move AGVS to 1st AS/RS
1420 PL1 = 4 : GOSUB 4470 : 'program to move AS/RS rack to AGVS
1430 GOSUB 4130 : ' program to lift the part
1440 LP1=2:GOSUB 4210 : 'Place the part at 1st position
1450 GOSUB 4380 : 'program to place part at 1st AS/RS
1460 ZZ$="6": GOSUB 8380 : ' part from waiting line to lathe 1
1470 GOSUB 7710 : 'moves the AGVS backwards beyond 1st M/C center
1480 GOSUB 6940 : 'moves the AGVS to 1st M/C center
1490 KK=1 : GOSUB 6510 : ' IInd M/C & moves 1st M/C rack back
1500 ZZ$="2" : GOSUB 8380 :move part from lathe1 to lathe2
1510 GOSUB 7440 : 'moves AGVS to 1st AS/RS
1520 OUT(&H300),0:PL1=2 : GOSUB 4470 :
1530 ZZ$="3" : GOSUB 8380 : 'moves part from lathe2 to washer
1540 GOSUB 4130 : 'picks up part at 1st AS/RS
1550 GOSUB 7610 : 'moves AGVS back to ROBOTIC CELL
1560 ZZ$ ="4" : GOSUB 8380 : moves part from washer onto AGVS
1570 LP1=4 : GOSUB 4210 : ' 1st AS/RS rack is placed at 3rd posn
1580 GOSUB 4380 : ' to place part at 1st AS/RS
1590 GOSUB 7340 : 'moves AGVS to IInd AS/RS
1600 ZZ$="6":GOSUB 8380 : ' waiting line to LATHE1
1610 INPUT #3,PL2:GOSUB 4880 : ' move AS/RS rack to AGVS
1620 GOSUB 4600 : ' pick up part at IInd AS/RS from AGVS
1630 LP2=2:GOSUB 4690 : 'to storage #1 at 1st AS/RS from AGVS
1640 GOSUB 4810: ' place part at posn 1 at IInd AS/RS
1650 ZZ$="5":GOSUB 8380 : ' part from turntable to waiting line
1660 GOSUB 7810 : ' stop AGVS at 1st M/C CENTER backwards
1670 GOSUB 7040 : ' program to stop AGVS at IInd M/C CENTER
1680 ZZ$="2":GOSUB 8380 : ' move part from LATHE1 to LATHE2
1690 GOSUB 6650 : ' part on top of AGVS at IInd M/C CENTER
1700 GOSUB 7340 : 'AGVS from IInd M/C CENTER to IInd AS/RS
1710 ZZ$="3":GOSUB 8380 : ' move part from LATHE2 to WASHER
1720 PL2=2:GOSUB 4880 : 'move IInd AS/RS to AGVS
1730 GOSUB 2060 : 'program to pick up part at IInd AS/RS
1740 GOSUB 7610 : ' move AGVS from IInd AS/RS to ROBOTIC-CELL
1750 ZZ$="4":GOSUB 8380:'places part on top of AGVS
1760 LP2=4:GOSUB 4690 : ' move part at IInd AS/RS to posn 3
1770 GOSUB 4810 : ' place part at posn 3 at IInd AS/RS
1780 GOSUB 7240 : ' move AGVS from R.CELL to IIIrd AS/RS
1790 PL3=4: GOSUB 5270 : ' move IIIrd AS/RS to AGVS
1800 GOSUB 5000 : 'program to lift part at IIIrd AS/RS
1810 LP3=2:GOSUB 5100 : ' move part from AGVS to IIIrd AS/RS
1820 GOSUB 5200 : 'place part at IIIrd AS/RS
1830 GOSUB 7910: 'stop AGVS at IInd M/C CENTER backwards
1840 GOSUB 7140 : 'program to stop AGVS at IIIrd M/C CENTER

```

Figure 20 (continued)

```

1850 ZZ$="1":GOSUB 8380 : 'part from PART LOADER to LATHE1
1860 GOSUB 6790 : 'part on top of AGVS at IIIRD M/C CENTER
1870 GOSUB 7240 : 'AGV from IIIRD M/C CENTER to IIIRD AS/RS
1880 PL3=2:GOSUB 5240: 'brings IIIRD AS/RS to AGVS
1890 GOSUB 5000 : 'IIIRD AS/RS picks up part from AGVS
1900 LP3=4:GOSUB 5100 : 'part to IIIRD posn at IIIRD AS/RS
1910 GOSUB 5200 : 'place part at IIIRD AS/RS
1920 ZZ$="2":GOSUB 8380 : 'part from LATHE1 to LATHE2
1930 PL1=3:GOSUB 4470 : ' 1st AS/RS backwards
1940 LP1=2:GOSUB 4210 : '1st AS/RS moves to posn 1
1950 X1=7:GOSUB 3880 : '1st part at 1st AS/RS is picked up
1960 ZZ$="3":GOSUB 8380 : ' part from LATHE2 to WASHER
1970 GOSUB 7610 : ' AGVS from IIIRD AS/RS to ROBOTIC CELL
1980 ZZ$="4":GOSUB 8380: ' places part on top of AGVS
1990 X1=7:GOSUB 3880 : 'part #1 at AS/RS 1 to part loader
2000 GOSUB 7440 : ' part from ROBOTIC-CELL to 1st AS/RS
2010 GOSUB 5390 : 'pick-up part at part loader from AS/RS cart
2020 GOSUB 5650 : 'part from AS/RS to AGVS at PART LOADER
2030 PL1=6:GOSUB 4470
2040 ZZ$="1":GOSUB 8380
2050 GOSUB 8120 : 'program to turn TURN TABLE
2060 GOSUB 5940 : ' program to move part to 1st M/C center
2070 OUT(&H300),16 : 'turns M/C 1 on.
2080 ZZ$="2":GOSUB 8380: ' move part from lathe1 to lathe2
2090 GOSUB 4130 : 'program to lift part at 1st AS/RS
2100 LP1=3:GOSUB 4210: 'program to place AS/RS 1 to posn 2
2110 GOSUB 4380 : 'place part at posn 2 at 1st AS/RS
2120 ZZ$="3":GOSUB 8380: ' move part from lathe2 to washer
2130 GOSUB 7610 : ' move AGVS from AS/RS 1 to ROBOTIC CELL
2140 OUT(&H300),0 : 'program to switch M/C 1 off
2150 ZZ$="4":GOSUB 8380 : ' move part from washer to AGVS
2160 GOSUB 7340 : 'moves AGVS to IIRD AS/RS
2170 PL2=4:GOSUB 4690: ' program to move AS/RS 2 to AGVS
2180 ZZ$="1":GOSUB 8380 : 'part from turn table to lathe1
2190 GOSUB 2060 : 'program to pick up part at IIRD AS/RS
2200 LP2=3:GOSUB 4690 : 'move part at IIRD AS/RS to posn 2
2210 GOSUB 4810 : 'place part at posn 2 at IIRD AS/RS
2220 ZZ$="2":GOSUB 8380: 'move part from lathe1 to lathe2
2230 GOSUB 7610 : 'program to move AGVS to ROBOTIC CELL
2240 ZZ$="3":GOSUB 8380: ' part from lathe2 to washer
2250 GOSUB 8820 : 'delay of 18 secs
2260 ZZ$="4":GOSUB 8380: ' put part on top of AGVS
2270 GOSUB 7240: ' move AGVS to AS/RS III
2280 PL3=4:GOSUB 5240: ' move AS/RS III to AGVS
2290 GOSUB 5000 : ' pick up part at IIIRD AS/RS
2300 LP2=3 :GOSUB 5100 : ' IIIRD AS/RS from AGVS
2310 GOSUB 5270 : 'place at posn 2 at IIIRD AS/RS

```

Figure 20 (continued)

```

2320 GOSUB 7710 : ' move the AGVS beyond 1st M/C center
2330 GOSUB 6940 : ' stop AGVS at 1st M/C CENTER
2340 GOSUB 6510
2350 GOSUB 7440 : ' move AGVS to 1st M/C CENTER
2360 PL1=3:GOSUB 4470 : 'moves 1st AS/RS rack to AGVS
2370 GOSUB 4130: 'program to lift part at 1st AS/RS
2380 LP1=2:GOSUB 4220 : 'AGVS to posn 1 at 1st AS/RS
2390 GOSUB 4380 : 'part at posn 1 at 1st AS/RS
2400 PL2=3:GOSUB 4880 : ' move AS/RS II to posn 1
2410 LP2=2:GOSUB 4600
2420 GOSUB 3640
2430 GOSUB 5390 : ' lift part at PART-LOADER
2440 GOSUB 5650 : 'move part to AGVS at PART LOADER
2450 OUT(&H300),16:GOSUB 5940
2460 PL2=5:GOSUB 4880 : 'move IInd AS/RS rack to posn 1
2470 PL3=3:GOSUB 5270 : 'program to move to initial posn
2480 LP3=2:GOSUB 5080 : 'program to move part to posn 1
2490 X1=7 : GOSUB 3360
2500 GOSUB 5390 : ' move PART LOADER to AS/RS cart
2510 GOSUB 5650 : 'at PART LOADER from AS/RS cart to AGVS
2520 GOSUB 6120 : ' move part to IInd M/C CENTER
2530 OUT(&H300),48: ' turns motors 1 & 2 ON
2540 PL3=5: ' move IIIrd AS/RS rack to posn 1
2550 LP1=2: GOSUB 4220 : ' move AS/RS 1 to posn 2
2560 X1=6:GOSUB 3880 : ' move part #2 to part loader
2570 GOSUB 5390
2580 GOSUB 5650 : AS/RS cart to AGVS at PART LOADER
2590 OUT(&H300),33:GOSUB 6300 : 'part from PART LOADER
2600 PL1=6:GOSUB 4470 : 'move AS/RS rack to initial posn
2610 GOSUB 6940 : 'moves AGVS to M/C CENTER 1
2620 GOSUB 6510 : 'unloading at 1st M/C CENTER
2630 GOSUB 7340 : 'moves part on AGVS to IInd AS/RS
2640 PL2=2:GOSUB 4470: 'move IInd AS/RS rack to AGVS
2650 GOSUB 4600 : 'program to lift part at IInd AS/RS
2660 LP2=2:GOSUB 4690
2670 GOSUB 4810 : ' place part at posn 2 at IInd AS/RS
2680 OUT(&H300),1:GOSUB 7790
2690 GOSUB 7040 : ' move AGVS to IInd M/C CENTER
2700 GOSUB 6650 : 'unloading at IInd M/C CENTER
2710 GOSUB 7240 : 'program to move AGVS to IIIrd AS/RS
2720 PL3=2:GOSUB 5270: 'move IIIrd AS/RS rack to AGVS
2730 GOSUB 5000 : 'lift part at IIIrd AS/RS from AGVS
2740 LP3=2: GOSUB 5080 : 'part at IIIrd AS/RS from AGVS
2750 GOSUB 5200 : 'place part at posn 1 at IIIrd AS/RS
2760 OUT(&H300),0: GOSUB 7910 : 'stop AGVS beyond IIIrd M/C
2770 GOSUB 7140 : ' stop AGVS at IIIrd M/C
2780 GOSUB 6790 : 'unloading at IIIrd M/C CENTER

```

Figure 20 (continued)

```

2790 GOSUB 7440 : 'move part from IIIrd M/C to 1st AS/RS
2800 GOSUB 4130 : ' lift part at 1st AS/RS from AGVS
2810 LP1=3:GOSUB 4220 : ' 1st AS/RS from AGVS to posn 2
2820 GOSUB 4380 : 'place part at posn 2 at 1st AS/RS
2830 LP2=2:GOSUB 4690 : ' move IInd AS/RS to posn 2
2840 X2=6:GOSUB 3640: ' move part to part loader
2850 GOSUB 5390
2860 GOSUB 5650
2870 GOSUB 5940 : ' move part to 1st M/C CENTER
2880 OUT(&H300),16 : 'program to start M/C 1
2890 PL2=6: GOSUB 4880 : 'IInd AS/RS rack to i.posn
2900 LP3=2:GOSUB 5080 : 'pick up part at posn 2
2910 X3=6:GOSUB 3360 : ' AS/RS to PART LOADER
2920 GOSUB 5390
2930 GOSUB 5650
2940 GOSUB 6120 : 'move part to IInd M/C Center
2950 OUT(&H300),48 : 'switches M/C 1 & M/C 2
2960 PL3=6:GOSUB 5270: ' III AS/RS to initial posn
2970 PL1=3:GOSUB 4470: 'move 1st AS/RS to initial posn
2980 LP1=2:GOSUB 4220: ' move 1st AS/RS to posn 1
2990 X1=7:GOSUB 3880 : 'part 1 at 1st AS/RS to part loader
3000 GOSUB 5390
3010 GOSUB 5650
3020 GOSUB 6300 : 'move part to IIIrd M/C CENTER
3030 OUT(&H300),33: 'switch M/C 1 off & switch 2 & 3 ON
3040 PL1=6:GOSUB 4470: 'move 1st AS/RS to initial posn
3050 GOSUB 7710 : 'moves AGVS beyond 1st M/C center
3060 GOSUB 6940 : 'stops AGVS at 1st M/C
3070 GOSUB 6510 : 'push part on top of AGVS at 1st M/C
3080 GOSUB 7340 : 'move AGVS to IInd AS/RS
3090 GOSUB 4600 : 'pick up part from AGVS at IInd AS/RS
3100 LP2=3:GOSUB 4690 : 'move IInd AS/RS to posn 2
3110 GOSUB 4810 : 'place part at IInd AS/RS at posn 2
3120 OUT(&H300),1: 'stop 2nd M/C
3130 GOSUB 7790 : 'move AGVS beyond IInd M/C
3140 GOSUB 7040 : 'stop AGVS at IInd M/C
3150 GOSUB 6650 : 'unload part onto AGVS at IInd M/C
3160 GOSUB 7240 : 'move part on AGVS to IIIrd AS/RS
3170 GOSUB 5000 : 'lift part at IIIrd AS/RS
3180 LP3=3: GOSUB 5080 : 'AGV to 2nd posn at IIIrd AS/RS
3190 GOSUB 5200 : 'place part at posn 2 at IIIrd AS/RS
3200 OUT(&H300),0:
3210 GOSUB 7910 : 'move AGVS beyond 3rd M/C
3220 GOSUB 7140 : 'move AGVS to IIIrd M/C
3230 GOSUB 6790 : 'move part on top of AGVS at 3rd M/C
3240 GOSUB 7440 : 'move AGVS to 1st AS/RS
3250 GOSUB 4130 : 'pick up part at 1st AS/RS from AGVS

```

Figure 20 (continued)

```

3260 LP1=2:GOSUB 4220 : 'move part at 1st AS/RS to posn 1
3270 GOSUB 4380 : 'place part at posn 1 at 1st AS/RS
3280 PL2=3:GOSUB 4880: 'move AS/RS II to initial posn
3290 LP2=2:GOSUB 4690 : 'move AS/RS II to posn 1
3300 X2=7:GOSUB 3640: 'part I at IIInd AS/RS to PART LOADER
3310 '
3320 GOSUB 5390
3330 GOSUB 5650
3340 GOTO 9680
3350 '
3360 REM : III AS/RS from storage & move to AS/RS cart
3370 '
3380 CUT=0
3390 OUT(&H381),64 : OUT(&H380),1
3400 X=1015:GOSUB 11440
3410 OUT(&H381),192:X=1020:GOSUB 11570
3420 OUT(&H200),168
3430 A=INP(&H202)
3440 IF (A AND 128)=128 THEN 3450 ELSE 3430
3450 CUT=CUT+1:IF CUT=X3-COUNT THEN 3470 ELSE 3460
3460 X=1043:GOSUB 11570
3470 OUT(&H200),40:OUT(&H380),33
3480 A=INP(&H201)
3490 IF (A AND 1)=1 THEN 3500 ELSE 3480
3500 OUT(&H380),1:OUT(&H381),64:X=1060:GOSUB 11570
3510 OUT(&H380),0:X=1065:GOSUB 11570
3520 OUT(&H381),192:OUT(&H380),16
3530 A=INP(&H382)
3540 IF (A AND 128)=128 THEN OUT(&H380),0 ELSE 3530
3550 RETURN
3560 '
3570 '
3580 '
3590 ' SUBROUTINES BEGIN FROM HERE
3600 '
3610 '
3620 '*****
3630 '
3640 REM : program to lift part at II AS/RS from
3645 ' storage & move to AS/RS cart
3650 '
3660 CU=0
3670 OUT(&H200),41 : OUT(&H381),32
3680 X=1215:GOSUB 11440
3690 OUT(&H200),43:X=1220:GOSUB 11570
3700 OUT(&H202),8
3710 A=INP(&H382)

```

Figure 20 (continued)

```

3720 IF (A AND 32)=32 THEN 3730 ELSE 3710
3730 CU=CU+1:IF CU=X2-KOUNT THEN 3750 ELSE 3740
3740 X=1245:GOSUB 11870
3750 OUT(&H202),0:OUT(&H380),32
3760 A=INP(&H201)
3770 IF (A AND 2)=2 THEN 3780 ELSE 3760
3780 OUT(&H380),0:OUT(&H200),41:X=1265:GOSUB 11440
3790 OUT(&H381),0:X=1270:GOSUB 11570
3800 OUT(&H380),43:OUT(&H380),16
3810 A=INP(&H382)
3820 IF (A AND 128)=128 THEN 3830 ELSE 3810
3830 OUT(&H380),0
3840 RETURN
3850 '
3860 '*****
3870 '
3880 REM : program to lift part at I AS/RS
3885 '   ' from storage & move to AS/RS cart
3890 '
3900 TU=0
3910 OUT(&H380),64 :OUT(&H200),32:OUT(&H380),64
3920 X=1415:GOSUB 11760
3930 OUT(&H200),40:X=1420:GOSUB 11760
3940 OUT(&H202),2
3950 A=INP(&H202)
3960 IF (A AND 64)=64 THEN 3970 ELSE 3950
3970 TU=TU+1:IF TU=X1-POUNT THEN 3990 ELSE 3980
3980 X=1440:GOSUB 11570
3990 OUT(&H202),0 :OUT(&H380),96
4000 '
4010 A=INP(&H201)
4020 IF (A AND 4)=4 THEN 4030 ELSE 4010
4030 OUT(&H380),64 :OUT(&H200),32:X=1460:GOSUB 11440
4040 OUT(&H380),0:X=1465:GOSUB 11570
4050 OUT(&H200),40:OUT(&H380),16
4060 A=INP(&H382)
4070 IF (A AND 128)=128 THEN 4080 ELSE 4060
4080 OUT(&H380),0
4090 RETURN
4100 '
4110 '*****
4120 '
4130 REM : program to lift part at Ist AS/RS from AGVS
4140 '
4150 OUT(&H200),32:OUT(&H380),64
4160 X=1615:GOSUB 11440
4170 OUT(&H200),40:X=1620:GOSUB 11440

```

Figure 20 (continued)

```

4180 OUT(&H202),0:RETURN
4190 '
4200 ' *****
4210 '
4220 REM :program to move part from AGVS
4225 '      to desired location on 1st AS/RS
4230 '
4240 POUNT=0
4250 OUT(&H202),2
4260 A=INP(&H202)
4270 IF (A AND 64)=64 THEN 4280 ELSE 4260
4280 POUNT=POUNT+1:IF POUNT = LP1 THEN 4300 ELSE 4290
4290 X=1680:GOSUB 11680
4300 OUT(&H202),0
4310 OUT(&H380),64 :OUT(&H200),32:X=1678:GOSUB 11440
4320 OUT(&H380),0:X=1679:GOSUB 11760
4330 OUT(&H200),40
4340 RETURN
4350 '
4360 ' *****
4370 '
4380 REM :program to place part at 1st AS/RS
4390 '
4400 OUT(&H202),0: OUT(&H200),32:X= 1685:GOSUB 11680
4410 OUT(&H380),0:X=1690:GOSUB 11680
4420 OUT(&H200),40:X=1695:GOSUB 11440
4430 RETURN
4440 '
4450 ' *****
4460 '
4470 REM :program to move 1st AS/RS rack
4475 '      from AS/RS cart to desired location
4480 '
4490 POUNT =0
4500 OUT(&H202),1
4510 A=INP(&H202)
4520 IF (A AND 64)=64 THEN 4530 ELSE 4510
4530 POUNT=POUNT+1:IF POUNT =PL1 THEN 4550 ELSE 4540
4540 X=1775 : GOSUB 11680
4550 OUT(&H202),0
4560 RETURN
4570 '
4580 ' *****
4590 '
4600 REM : program to lift part at IInd AS/RS from AGVS
4610 '
4620 OUT(&H200),41:OUT(&H381),32

```

Figure 20 (continued)

```

4630 X=1815:GOSUB 11440
4640 OUT(&H200),3:X=1820:GOSUB 11440
4650 OUT(&H200),0:RETURN
4660 '
4670 ' *****
4680 '
4690 REM : program to move part from AGVS
4695 '      to desired location on IInd AS/RS
4700 '
4710 KOUNT=0
4720 OUT(&H202),8
4730 A=INP(&H382)
4740 IF (A AND 32)=32 THEN 4750 ELSE 4730
4750 KOUNT=KOUNT+1:IF KOUNT = LP2 THEN 4770 ELSE 4760
4760 X=1875:GOSUB 11680
4770 OUT(&H202),0:RETURN
4780 '
4790 ' *****
4800 REM :program to pick-up part at IInd AS/RS
4805 '
4810 OUT(&H202),0:OUT(&H200),1:X=1880:GOSUB 11680
4820 OUT(&H381),32:X=1885:GOSUB 11680
4830 OUT(&H200),43:X=1890:GOSUB 11440
4840 RETURN
4850 '
4860 ' *****
4870 '
4880 REM :program to move IInd AS/RS rack
4885 '      from AS/RS cart to desired loaction
4890 '
4900 KOUNT=0
4910 OUT(&H202),4
4920 A=INP(&H382)
4930 IF (A AND 32)=32 THEN 4940 ELSE 4920
4940 KOUNT=KOUNT+1:IF KOUNT=PL2 THEN 4960 ELSE 4950
4950 X=1936:GOSUB 11680
4960 OUT(&H202),0
4970 RETURN
4980 ' *****
4990 '
5000 REM : program to lift part at IIIrd AS/RS from AGVS
5010 '
5020 OUT(&H381),64 :OUT(&H380),1
5030 X=1947 : GOSUB 11440
5040 OUT(&H381),192:X=1949:GOSUB 11680
5050 OUT(&H381),0
5060 RETURN

```

Figure 20 (continued)

```

5070 '
5080 '*****
5090 '
5100 REM : program to move part at IIrd AS/RS
5105 'from AGVS to desired location
5110 '
5120 OUT(&H200),168
5130 COUNT=0
5140 A=INP(&H202)
5150 IF (A AND 128)=128 THEN 5160 ELSE 5140
5160 COUNT=COUNT+1: IF COUNT = LP3 THEN 5180 ELSE 5170
5170 X=1968 : GOSUB 11680
5180 OUT(&H200),40:RETURN
5190 '
5200 OUT(&H381),64 : X=1970 : GOSUB 11680
5210 OUT(&H380),0:X=1972 :GOSUB 11680
5220 OUT(&H381),192 : X=1974 : GOSUB 11680
5230 OUT(&H381),0:RETURN
5240 '
5250 '*****
5260 '
5270 REM : program to move IIrd AS/RS rack
5275 '      from AS/RS cart to desired location
5280 '
5290 OUT(&H200),104
5300 COUNT=0
5310 A=INP(&H202)
5320 IF (A AND 128)=128 THEN 5330 ELSE 5310
5330 COUNT=COUNT+1: IF COUNT=PL3 THEN 5350 ELSE 5340
5340 X=1993 : GOSUB 11680
5350 OUT(&H200),40:RETURN
5360 '
5370 '*****
5380 '
5390 REM :program for part loader
5395 ' to pick-up part from AS/RS
5400 '
5410 OUT(&H381),4
5420 A=INP(&H301)
5430 IF (A AND 128)=128 THEN 5440 ELSE 5420
5440 OUT(&H381),0:OUT(&H381),1:OUT(&H380),8
5450 X=2025:GOSUB 11440
5460 OUT(&H381),3:X=2030:GOSUB 11440
5470 OUT(&H381),0
5480 RETURN
5490 '
5500 ' *****

```

Figure 20 (continued)

```

5510 '
5520 REM : program to move part at part loader
5525 ' from AS/RS cart to TURNTABLE
5530 OUT(&H381),4
5540 L1=TIMER+7.76
5550 I1=2
5560 IF TIMER >=L1 THEN 5570 ELSE 5550
5570 OUT(&H381),1:X=2120:GOSUB 11570
5580 OUT(&H380),0:X=2125:GOSUB 11570
5590 OUT(&H381),3:X=2130:GOSUB 11440
5600 OUT(&H381),0
5610 RETURN
5620 '
5630 '*****
5640 '
5650 REM : program to move part at PART-LOADER to AGVS
5660 '
5670 OUT(&H381),8
5680 A=INP(&H382)
5690 IF (A AND 8)=8 THEN 5700 ELSE 5680
5700 IF XA=1 THEN 5750 ELSE 5710
5710 OUT(&H381),1:X=2225:GOSUB 11570
5720 OUT(&H380),0:X=2230:GOSUB 11570
5730 OUT(&H381),3:X=2235:GOSUB 11440
5740 OUT(&H381),0
5750 XA=0:RETURN
5760 '
5770 ' *****
5780 '
5790 REM:program to move PART-LOADER
5795 ' from TURN-TABLE to AS/RS cart
5800 '
5810 OUT(&H381),8
5820 A=INP(&H301)
5830 IF (A AND 128)=128 THEN 5840 ELSE 5820
5840 X=2322:GOSUB 11440
5850 OUT(&H381),1:X=2325:GOSUB 11570
5860 OUT(&H380),0:X=2330:GOSUB 11570
5870 OUT(&H381),3:X=2335:GOSUB 11570
5880 X=2340:GOSUB 11760
5890 OUT(&H381),0
5900 RETURN
5910 '
5920 ' *****
5930 '
5940 REM program to move part from
5945 ' PART-LOADER to M/C CENTER 1

```

Figure 20 (continued)

```

5950 '
5960 OUT(&H380),128
5970 B=INP(&H301)
5980 IF (B AND 4)=4 THEN OUT(&H380),0 ELSE 5970
5990 OUT(&H302),1
6000 X=3030 : GOSUB 12030
6010 OUT(&H380),4
6020 B=INP(&H201)
6030 IF (B AND 16)=16 THEN 6040 ELSE 6020
6040 OUT(&H380),0
6050 A=INP(&H382)
6060 IF (A AND 64)=64 THEN 6070 ELSE 6050
6070 OUT(&H302),0
6080 RETURN
6090 '
6100 ' *****
6110 '
6120 REM : program to move part
6125 '      from PART-LOADER to M/C CENTER 2
6130 '
6140 OUT(&H380),128
6150 B=INP(&H301)
6160 IF (B AND 2)=2 THEN OUT(&H380),0 ELSE 6150
6170 HM=64 : GOSUB 9370
6180 X=3230:GOSUB 12030
6190 OUT(&H380),4
6200 B=INP(&H201)
6210 IF (B AND 16)=16 THEN 6220 ELSE 6200
6220 OUT(&H380),0
6230 A=INP(&H302)
6240 IF (A AND 16)=16 THEN 6250 ELSE 6230
6250 GOSUB 9530
6260 MM=0:RETURN
6270 '
6280 ' *****
6290 '
6300 REM : program to move part from
6305 '      PART-LOADER to III M/C CENTER
6310 '
6320 OUT(&H380),128
6330 B=INP(&H301)
6340 IF (B AND 1)=1 THEN OUT(&H380),0 ELSE 6330
6350 HM=128:GOSUB 9370
6360 X=3430 : GOSUB 12030
6370 OUT(&H380),4
6380 B=INP(&H301)
6390 IF (B AND 4)=4 THEN OUT(&H380),0 ELSE 6380

```

Figure 20 (continued)

```

6400 X=3442 : GOSUB 11940
6410 OUT(&H380),4
6420 A=INP(&H201)
6430 IF (A AND 16)=16 THEN OUT(&H380),0 ELSE 6420
6440 A=INP(&H302)
6450 IF (A AND 64)=64 THEN 6460 ELSE 6440
6460 GOSUB 9530
6470 MM=0:RETURN
6480 '
6490 '*****
6500 '
6510 REM : program to move part from
6515 ' 1st M/C CENTER onto AGVS
6520 '
6530 OUT(&H302),1
6540 X=3515:GOSUB 11760
6550 A=INP(&H382)
6560 IF (A AND 64)=64 THEN OUT(&H302),0 ELSE 6550
6570 OUT(&H200),4
6580 X=3529 : GOSUB 12030
6590 A=INP(&H382)
6600 IF (A AND 64)=64 THEN OUT(&H200),0 ELSE 6590
6610 RETURN
6620 '
6630 ' *****
6640 '
6650 REM :program to move part from
6655 ' 11nd M/C CENTER onto AGVS
6660 '
6670 OUT(&H300),64
6680 X=3565 : GOSUB 11680
6690 A=INP(&H302)
6700 IF (A AND 16)=16 THEN OUT(&H300),64 ELSE 6690
6710 OUT(&H300),0:OUT(&H380),2
6720 X=3579 : GOSUB 12030
6730 A=INP(&H302)
6740 IF (A AND 16)=16 THEN 6750 ELSE 6730
6750 RETURN
6760 '
6770 '*****
6780 '
6790 REM : program to move part
6795 ' from 111rd M/C CENTER onto AGVS
6800 HM=128 : GOSUB 9370
6810 X=3610 : GOSUB 11680
6820 A=INP(&H302)
6830 IF (A AND 64)=64 THEN 6840 ELSE 6820

```

Figure 20 (continued)

```

6840 GOSUB 9530
6850 HM=8:GOSUB 9370
6860 X=3634 : GOSUB 12030
6870 A=INP(&H302)
6880 IF (A AND 64)=64 THEN 6890 ELSE 6870
6890 GOSUB 9530
6900 MM=0:RETURN
6910 '
6920 '*****
6930 '
6940 REM : program to move AGVS from
6945 '     ROBOTIC-CELL to M/C CENTER I .
6950 '
6960 HM=4:GOSUB 9370
6970 A=INP(&H301)
6980 IF (A AND 16)=16 THEN 6990 ELSE 6970
6990 GOSUB 9530
7000 RETURN
7010 '
7020 '*****
7030 '
7040 REM : program to move AGVS from
7045 '     ROBOTIC-CELL to M/C CENTER II
7050 '
7060 HM=4 : GOSUB 9370
7070 A=INP(&H301)
7080 IF (A AND 8)=8 THEN 7090 ELSE 7070
7090 GOSUB 9530
7100 RETURN
7110 '
7120 '*****
7130 '
7140 REM : program to move AGVS
7145 '     from ROBOTIC-CELL to M/C CENTER III
7150 '
7160 HM=4:GOSUB 9370
7170 A=INP(&H301)
7180 IF (A AND 32)=32 THEN 4223 ELSE 7170
7190 STOP
7200 GOSUB 9530
7210 '
7220 '*****
7230 '
7240 REM : program to move part on AGVS to III AS/RS
7250 '
7260 HM=4:GOSUB 9370
7270 A=INP(&H201)

```

Figure 20 (continued)

```

7280 IF (A AND 128)=128 THEN 7290 ELSE 7270
7290 GOSUB 9530
7300 PP=0:RETURN
7310 '
7320 '*****
7330 '
7340 REM : program to move part on AGVS to II AS/RS
7350 '
7360 HM=4 : GOSUB 9370
7370 A=INP(&H201)
7380 IF (A AND 32)=32 THEN 7390 ELSE 7370
7390 GOSUB 9530
7400 PP=0:RETURN
7410 '
7420 '*****
7430 '
7440 REM :program to move part on AGVS to 1st AS/RS
7450 '
7460 HM=4:GOSUB 9370
7470 A=INP(&H201)
7480 IF (A AND 32)=32 THEN 7490 ELSE 7470
7490 GOSUB 9530
7500 O=TIMER+.3
7510 II=1
7520 IF TIMER>=O THEN 7530 ELSE 4522
7530 HM=4:GOSUB 9370
7540 A=INP(&H201)
7550 IF (A AND 64)=64 THEN 7560 ELSE 7540
7560 GOSUB 9530
7570 RETURN
7580 '
7590 '*****
7600 '
7610 REM : program to stop AGVS at ROBOTIC CELL
7620 '
7630 HM=2:GOSUB 9370
7640 A=INP(&H382)
7650 IF (A AND 2)=2 THEN 7660 ELSE 7640
7660 GOSUB 9530
7670 RETURN
7680 '
7690 '*****
7700 '
7710 'program to stop AGVS backwards at 1st M/C CENTER
7720 '
7730 HM=2 : GOSUB 9370
7740 A=INP(&H301)

```

Figure 20 (continued)

```

7750 IF (A AND 16)=16 THEN 7760 ELSE 7740
7760 X=4655:GOSUB 11440
7770 RETURN
7780 '
7790 '*****
7800 '
7810 'program to move AGVS backwards to M/C CENTER II
7820 '
7830 HM=2 : GOSUB 9370
7840 A=INP(&H301)
7850 IF (A AND 16)=16 THEN 7860 ELSE 7840
7860 X=GOSUB 11440
7870 RETURN
7880 '
7890 ' *****
7900 '
7910 REM : program to move AGVS to M/C CENTER III
7920 '
7930 HM=2 : GOSUB 9370
7940 A=INP(&H301)
7950 IF (A AND 8)=8 THEN 7960 ELSE 7940
7960 X=4707 : GOSUB 5390
7970 RETURN
7980 '
7990 ' *****
8000 '
8010 REM :program for testing
8020 '
8030 OUT(&H300),1
8040 A=INP(&H201)
8050 IF (A AND 64)=64 THEN 8060 ELSE 8040
8060 OUT(&H300),0
8070 STOP
8080 '
8090 '*****
8100 '
8110 REM :program to move the TURNTABLE one position
8120 '
8130 PT=3
8140 OUT(&H381),16
8150 FOR ZI=1 TO PT
8160 K=K+1
8165 IF (K=1) OR (K=2) OR (K=3) THEN ABC=.65 ELSE ABC=.64
8170 L3=TIMER+ABC
8180 II=2
8190 IF TIMER>=L3 THEN 8210 ELSE 8180
8200 X=6020:GOSUB 11760

```

Figure 20 (continued)

```

8230 PT=1:RETURN
8240 '
8250 ' program to move the TURNTABLE
8260 '
8270 OUT(&H381),16
8280 TP=0
8290 A=INP(&H201)
8300 IF (A AND 8)=8 THEN 8310 ELSE 8290
8310 TP=TP+1:IF TP=PT THEN 8330 ELSE 8320
8320 X=6070:GOSUB 11760
8330 OUT(&H381),0
8340 RETURN
8350 '
8360 ' *****
8370 '
8380 REM : down-load program of robot
8390 '
8400 DEFINT A-Z
8410 '
8420 '
8430 '----- Up-loading from robot to files:
8440 '
8450 CLS
8460 TOT.MOVES = 0
8470 ROUTINE = 0
8480 IF ZZ$="1" THEN LET DOWNFILE$="MAC1" :
8485 IF ZZ$="2" THEN DOWNFILE$="MAC2"
8486 IF ZZ$="3" THEN DOWNFILE$="WASHER"
8487 IF ZZ$="4" THEN DOWNFILE$="DR"
8488 IF ZZ$="5" THEN DOWNFILE$="WAIT"
8489 IF ZZ$="6" THEN DOWNFILE$="MID"
8490 '
8500 CLOSE #2 : OPEN DOWNFILE$ FOR INPUT AS #2
8510 WHILE (EOF(2)=0)
8520 INPUT #2 ,L1,L2,L3,L4,L5,L6,L7,L8
8530 PRINT#1,"@RESET":INPUT#1,I
8540 PRINT#1,"@QWRITE",L1,L2,L3,L4,L5,L6,L7,L8:INPUT#1,I
8550 WEND
8560 '
8570 ' >>>>>> EXECUTION ROUTINE <<<<<<<<<<<<
8580 '
8590 PRINT#1,"@RUN",PNT(ROUTINE):INPUT#1,I
8600 RETURN
8610 '
8620 ' *****
8630 '
8640 REM :program for lathe 1 at robotic-cell

```

Figure 20 (continued)

```

8650 '
8660 TIME$="0:0:00"
8670 T$=RIGHT$(TIME$,2)
8680 IF T$="59" THEN 8850 ELSE 8830
8690 RETURN
8700 '
8710 '*****
8720 '
8730 REM :program for lathe 2 at robotic-cell
8740 '
8750 TIME$="0:0:00"
8760 T$=RIGHT$(TIME$,2)
8770 IF T$="28" THEN 8850 ELSE 8830
8780 RETURN
8790 '
8800 '*****
8810 '
8820 REM :program for washer at robotic-cell
8830 '
8840 TIME$="0:0:00"
8850 T$=RIGHT$(TIME$,2)
8860 IF T$="18" THEN 8850 ELSE 8830
8870 RETURN
8880 '
8890 '*****
8900 '
8910 REM : program to entertain emergency stop
8920 '
8930 OUT(&H203),&H8A
8940 OUT(&H201),0
8950 CLS
8960 KEY ON :LOCATE 12,15 : PRINT "EMERGENCY STOP"
8970 END
8980 '
8990 '*****
9000 '
9010 REM : initialization of ports
9020 '
9030 OUT(&H303),&H8A : OUT(&H383),&H89 : OUT(&H200),40
9040 LOCATE 15,10 : PRINT "PRESS RETURN TO CONTINUE"
9050 LA$=INPUT$(1)
9060 IF LA$=CHR$(13) THEN 9070 ELSE 9050
9070 CLS :RETURN
9080 STOP
9090 RETURN
9100 '
9110 '*****

```

Figure 20 (continued)

```

9120 '
9130 REM :subroutine of subroutine for part-loader
9140 '
9150 GOSUB 5390
9160 PRINT "PART-LOADER MOVES TO PLACE PART ON TURNTABLE"
9170 GOSUB 5520
9180 PT=1:GOSUB 8120
9190 PRINT "PART-LOADER MOVES BACK" :GOSUB 5790
9200 RETURN
9210 '
9220 ' *****
9230 '
9240 REM :program to read sequential data file
9250 '
9260 OPEN "0", #3, "SEQ"
9270 FOR I=1 TO 30
9280 READ A: PRINT #3,A:NEXT I
9290 CLOSE #3
9300 DATA 2,7,5,2,6,4,2,7,5,2,6,4,2,7,5,2,6,4
9310 DATA 2,5,3,2,5,3,2,5,3 : 'part 3 moves to M/C center
9320 DATA 4,2,2 : 'program to run the turntable
9330 RETURN
9340 '
9350 ' *****
9360 '
9370 REM :program to run M/C's & H300 motors simultaneously
9380 '
9390 HS=16+HM:GOTO 9480
9400 HS=32+HM:GOTO 9480
9410 HS=1+HM:GOTO 9480
9420 HS=48+HM:GOTO 9480
9430 HS=17+HM:GOTO 9480
9440 HS=33+HM:GOTO 9480
9450 HS=49+HM:GOTO 9480
9460 HS=HM:GOTO 9480
9470 OUT(&H300),HS
9480 MM=0 : RETURN
9490 MM=0 : RETURN
9500 '
9510 ' *****
9520 '
9530 REM :program to run M/C's and stop the other motors
9540 '
9550 CH=16 : GOTO 9640
9560 CH=32 : GOTO 9640
9570 CH=1 : GOTO 9640
9580 CH=48 : GOTO 9640
9590 CH=17 : GOTO 9640
9600 CH=33 : GOTO 9640

```

Figure 20 (continued)

```

9610 CH=33 : GOTO 9640
9620 CH=49 : GOTO 9640
9630 CH=0 : GOTO 9640
9640 OUT(&H300),CH
9650 '
9660 ' *****
9670 '
9680 REM : continuation of the main program
9690 '
9700 GOSUB 5940 : 'move part to 1st M/C
9710 PL2=6:GOSUB 4880 : 'move IInd AS/RS to initial posn
9720 PL3=3:GOSUB 5270 : 'move IIIRD AS/RS to initial posn
9730 *LP3=2:GOSUB 5080 : 'move IIIRD AS/RS to posn 1
9750 GOSUB 5390
9760 GOSUB 5650
9770 GOSUB 6120 : 'move part from PART LOADER to M/C 2
9780 PL3=6:GOSUB 5270 : 'move IIIRD AS/RS to initial posn
9790 LP1=2:GOSUB 4220 : 'move 1st AS/RS to posn 2
9810 GOSUB 5390
9820 GOSUB 5650
9830 GOSUB 6300 : 'move part part from PART LOADER to M/C 3
9840 PL1=6:GOSUB 4470 : 'move 1st AS/RS to initial posn
9850 OUT(&H300),33 : 'switches M/C 1 off & turns 2 & 3 on
9860 GOSUB 7710 : 'move AGVS beyond 1st M/C
9870 GOSUB 6940 : 'move AGVS to 1st M/C
9880 GOSUB 6510 : 'unload part onto AGVS at 1st M/C
9890 GOSUB 7340 : 'move AGVS to IInd AS/RS
9900 GOSUB 4600 : 'lift part from AGVS at IInd AS/RS
9910 LP2=2:GOSUB 4690 : 'move IInd AS/RS to posn 1
9920 GOSUB 4810 : 'place part at IInd AS/RS at 1st posn
9930 OUT(&H300),1:SWITCHES M/C 2 OFF
9940 GOSUB 7790 : 'move AGVS to 1st M/C
9950 GOSUB 7040 : 'moves AGVS to M/C 2
9960 GOSUB 6650 : 'part at IInd M/C is unloaded onto AGVS
9970 GOSUB 7240 : 'move AGVS to IIIRD AS/RS
9980 GOSUB 5000 : 'lift part from AGVS at IIIRD AS/RS
9990 LP3=2:GOSUB 5080 : 'move part to posn 1 at IIIRD AS/RS
10000 GOSUB 5200 : 'place part at posn 1 at IIIRD AS/RS
10010 OUT(&H300),0 : 'stop M/C 3 off
10020 GOSUB 7910 : 'move AGVS to IInd M/C
10030 GOSUB 7140 : 'move AGVS to IIIRD M/C
10050 GOSUB 7440 : 'move AGVS to 1st AS/RS
10060 PL1=2:GOSUB 4470 : 'move 1st AS/RS to AGVS
10070 GOSUB 4130 : 'lift part from AGVS
10090 GOSUB 4380 : 'place part at 2nd posn at 1st AS/RS
10100 LP2=2:GOSUB 4690 : 'move IInd AS/RS to 2nd posn
10120 GOSUB 5390

```

Figure 20 (continued)

```

10130 GOSUB 5650
10140 GOSUB 5940 : 'move part from PART LOADER to 1st M/C
10150 OUT(&H300),16
10160 PL2=6:GOSUB 4880 : 'move IInd AS/RS to initial posn
10170 LP3=2:GOSUB 5080 : 'move IIIRD AS/RS to posn 2
10190 GOSUB 5390
10200 GOSUB 5650
10210 GOSUB 6120 : 'move part from PART LOADER to M/C 2
10220 OUT(&H300),48
10230 PL3=6:GOSUB 5270 : 'move IIIRD AS/RS to initial posn
10240 O=TIMER+39
10250 II=2
10260 IF TIMER >= O THEN 10270 ELSE 10250
10270 OUT(&H300),32
10290 GOSUB 6940 : 'move AGVS to 1st M/C
10300 GOSUB 6510 : 'move part on top of AGVS at 1st M/C
10310 GOSUB 7340 : 'move AGVS to IInd AS/RS
10320 GOSUB 4600 : 'lift part from AGVS at IInd AS/RS
10340 GOSUB 4810 : 'place part at posn 2 at IInd AS/RS
10350 OUT(&H300),32
10360 GOSUB 7790 : 'move AGVS to 1st M/C
10370 GOSUB 7040 : 'move AGVS to IInd M/C
10380 GOSUB 6650 : 'unload part on top of AGVS at IInd M/C
10390 GOSUB 7240 : 'move AGVS to IIIRD AS/RS
10400 GOSUB 5000 : 'lift part from AGVS at IIIRD AS/RS
10420 GOSUB 5200 : 'place part at 2nd posn at IIIRD AS/RS
10430 LP1=3:GOSUB 4220 : 'move AS/RS 1 to posn 4
10450 GOSUB 5390
10460 GOSUB 5650
10470 GOSUB 5940 : 'move part to M/C 1
10480 OUT(&H300),16
10490 PL1=6:GOSUB 4470 : 'move AS/RS 1 to initial posn
10500 LP2=3:GOSUB 4690 : 'move AS/RS II to posn 4
10520 GOSUB 5390
10530 GOSUB 5650
10540 GOSUB 6120 : 'move part to M/C 2
10550 OUT(&H300),48
10560 PL2=6:GOSUB 4880 : 'move AS/RS II to initial posn
10570 LP3=3:GOSUB 5080 : 'move AS/RS III to posn 4
10600 GOSUB 5650
10610 GOSUB 6300 : 'move part to M/C III
10620 OUT(&H300),49
10630 PL3=6:GOSUB 5270 : 'move AS/RS III to initial posn
10640 OP=TIMER+3000
10650 II=2
10660 IF TIMER>=OP THEN 14890 ELSE 14880
10670 OUT(&H300),33

```

Figure 20 (continued)

```

10680 GOSUB 7710 : 'move AGVS beyond M/C I
10690 GOSUB 6940 : 'moves AGVS to M/C I
10700 GOSUB 6510 : 'unloads part at 1st M/C
10710 GOSUB 7440 : 'move AGVS to 1st AS/RS
10720 GOSUB 4130 : 'AS/RS I lifts part from AGVS
10730 LP1=5:GOSUB 4220: 'moves part to posn 4 at 1st AS/RS
10740 GOSUB 4380 : 'part is placed at posn 4 at 1st AS/RS
10750 OUT(&H300),1
10760 GOSUB 7790: 'stop AGVS at M/C I
10770 GOSUB 7040 : 'stop AGVS at M/C II
10780 GOSUB 6650 : 'unload part at IInd M/C
10790 GOSUB 7340 : 'move AGVS to IInd AS/RS
10800 GOSUB 4600 : 'lift part from AGVS at IInd AS/RS
10810 LP2=5:GOSUB 4690 : 'moves AS/RS II to posn 4
10820 GOSUB 4810 : 'place part at IInd AS/RS at posn 4
10830 OUT(&H300),0
10840 GOSUB 7910 : 'moves AGVS to M/C II
10850 GOSUB 7140 : 'moves AGVS to M/C III
10860 GOSUB 6790 : 'unload part onto AGVS at IIInd M/C
10870 GOSUB 7240 : 'moves AGVS to AS/RS III
10880 GOSUB 5000 : 'lift part from AGVS at IIInd AS/RS
10890 LP3=5:GOSUB 5080 : 'move AS/RS III to posn 4
10900 GOSUB 5200 : 'place part at posn 4 at IIInd AS/RS
10910 X1=2:GOSUB 3880 : 'move part 4 at AS/RS to PART LOADER
10920 GOSUB 5390
10930 GOSUB 5650
10940 GOSUB 5940 : 'move part to M/C I
10950 OUT(&H300),16
10960 PL1=6 : GOSUB 4470 : 'move AS/RS I to initial posn
10980 GOSUB 5390
10990 GOSUB 5650
11000 GOSUB 6120 : 'move part to M/C II
11010 OUT(&H300),48
11020 PL2=6:GOSUB 4880 : 'move AS/RS II to initial posn
11040 GOSUB 5390
11050 GOSUB 5650
11060 GOSUB 6300 : 'move part to M/C III
11070 OUT(&H300),49
11080 PL3=6:GOSUB 5270 : 'move AS/RS III to initial posn
11090 OP=TIMER +30
11100 II=2
11110 IF TIMER >= OP THEN 11120 ELSE 11110
11120 OUT(&H300),33
11130 GOSUB 7710 : 'move AGVS beyond 1st M/C I
11140 GOSUB 6940 : 'move AGVS to M/C I
11150 GOSUB 6510 : 'unload part at 1st M/C I
11160 GOSUB 7440 : 'move AGVS to AS/RS I

```

Figure 20 (continued)

```

11170 GOSUB 4130 : 'lift part at AS/RS I
11180 LP1=5:GOSUB 4220 : 'move part to posn 4 at 1st AS/RS
11190 GOSUB 4380 : 'place part at posn 4 at 1st AS/RS
11200 OUT(&H300),1
11210 GOSUB 7790 : 'move AGVS to M/C I
11220 GOSUB 7040 : 'move AGVS to M/C 2
11230 GOSUB 6650 : 'unload part on top of AGVS at IInd M/C
11240 GOSUB 7340 : 'move AGVS to AS/RS II
11250 GOSUB 4600 : 'lift part at IInd AS/RS
11270 GOSUB 4810 : 'place part at posn 4 at IInd AS/RS
11280 OUT(&H300),0
11290 GOSUB 7910 : 'stop AGVS beyond M/C III
11300 GOSUB 7140 : 'stop AGVS at M/C III
11310 GOSUB 6790 : 'unload part at M/C III
11320 GOSUB 7240 : 'move AGVS to AS/RS III
11330 GOSUB 5000 : 'lift part from AGVS at IIIrd AS/RS
11340 LP3=5:GOSUB 5080 : 'move AS/RS III to posn 4
11350 GOSUB 5200 : 'place part at posn 4 at IIIrd AS/RS
11360 PL1=5:GOSUB 4470 : 'move AS/RS I to initial posn
11370 PL2=5:GOSUB 4880 : 'move AS/RS II to initial posn
11380 PL3=5:GOSUB 5270 : 'move AS/RS III to initial posn
11390 GOSUB 7610 : 'move AGVS to robotic cell
11400 END
11410 '
11420 ' *****
11430 '
11440 REM : delay of 2 seconds
11450 '
11460 L=TIMER+2
11470 II=1
11480 IF TIMER>=L THEN 11490 ELSE 11470
11520 IF X=1678 THEN RETURN 4320
11530 REM : delay of 2 seconds
11540 '
11550 ' *****
11560 '
11570 REM : delay of 1 second
11580 '
11590 L=TIMER+1
11600 II=1
11610 IF TIMER>=L THEN 11620 ELSE 11600
11660 '
11670 '
11680 REM : delay of 1 second
11690 '
11700 L=TIMER+1
11710 II=2

```

Figure 20 (continued)

```

11720 IF TIMER>=L THEN 11730 ELSE 11710
11760 REM : delay of 1 second
11770 '
11780 L=TIMER+1.3
11790 II=2
11830 IF X=3515 THEN RETURN 6550
11840 '
11850 REM :delay of 1.5 secs
11860 '
11870 L=TIMER+1.3
11880 II=2
11890 IF TIMER>=L THEN 11900 ELSE 11880
11900 RETURN 3710
11910 '
11920 ' *****
11930 '
11940 REM : delay of .7 secs
11950 '
11960 O = TIMER+.7
11970 II=1
11980 IF TIMER >= O THEN 11990 ELSE 11970
12000 '
12010 ' *****
12020 '
12030 REM : delay of 6 seconds
12040 '
12050 L=TIMER+6
12060 II=1
12070 IF TIMER>=L THEN 12080 ELSE 12060
12090 '
12100 OUT(&H381),16
12110 A=INP(&H382)
12120 IF (A AND 4)=4 THEN 12130 ELSE 12110
12130 TP=TP+1:IF TP=2 THEN 12150 ELSE 12140
12140 X=25035:GOSUB 11570
12150 OUT(&H381),0

```

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