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Manufacturing intelligent agent simulation has not been widely applied in industry because of its application complexity. This complexity, which includes choosing priority machines or jobs, determining machine maintenance schedules, and allocating working shifts and breaks, requires intelligent decision making. Manufacturing systems are strongly influenced by intelligent decision makers. Especially for a fixed manufacturing layout, system performance improvement depends on intelligent manufacturing decision making. As a result, a manufacturing simulation can not be truly complete if intelligent decision making processes are not represented. This thesis describes an

architecture which includes the representation of intelligent agents in manufacturing simulation model.

An intelligent agent simulation environment (IASE) is developed under the concepts of distributed artificial intelligence and object oriented methodology. As an extension to an existing simulation environment, IASE inherits primary manufacturing simulation elements and material handling systems from object oriented manufacturing architecture (Beaumariage, 1990) and AGV simulation system (Beaumariage and Wang, 1995). In IASE, production operators, maintenance technicians and job releasers are created to represent manufacturing intelligent agents. Several basic elements such as the blackboard structure and knowledge base for supporting intelligent agent simulation are also developed. In contrast to traditional simulation environments designed for and in procedural programming languages, future extensions or modifications for IASE are eased since IASE is developed in an object oriented fashion.

This paper introduces IASE structure both in the conceptual design and implementation methodology levels. At the end, two case studies are performed. The first case study is to verify IASE's implementation and results by comparing it with a model developed in SLAM II. The second case study, a mixed intelligent agent decision making example, demonstrates the intelligent agent simulation ability of IASE.

An Object Oriented Intelligent Agent Simulation Environment

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Chapter 1. Introduction

Most manufacturing simulation software emphasizes the interactions between entities such as parts, machines, and transportation tools. They assume that there is no intelligent intervention in. The queuing activity is treated very simplisticly, i.e. decision making as part of machine loading is typically ignored. In addition, machine break down situations are usually not considered or are modeled only stochastically. While dealing with priority policies, Traditional Manufacturing System Simulation Software (TMSSS) typically adopts FCFS (first come first served) or other simple rules since no decision making entities exist, hence simulation results of TMSSS will differ from actual systems. In other words, simulation results of TMSSS can always be predicted once the time of job-release events is known. In an equation, if $f(x)$ represents a manufacturing system modeled by TMSSS, then its simulation result can be interpreted as f(job-releasing time). Results of TMSSS are determined when job-releasing events occur because there is no factor involving decision making during run time. This remains true unless changing configurations of machines occurs, which is not realistic for simulating manufacturing plants.

In manufacturing factories, machine policies and job priorities are closely associated with system performance. These machine policies and job priorities are controlled by operations personnel (intelligent agents), therefore, it is important to develop a manufacturing simulation system supporting the representation of intelligent agents. The role of an intelligent agent normally is ignored by TMSSS; this could lead to a significant difference between a model (no IAs) and a system with intelligent personnel. If a manufacturing system applies different machine policies and job priorities than what is modeled, then the results will differ. The differences caused by applying different policies and priorities can be extremely important for factories with complicated manufacturing processes and high profit per throughput unit. It is valuable for factories to determine an optimal operations policy to maximize throughput. A simulation tool supporting intelligent agent representation can allow improved operating policies to be found.

In general manufacturing shop floors, there are two types of intelligent entities: production operators and maintenance technicians. Production operators take care of the transactions between parts and machines. They typically decide priority policies by choosing parts or setting up machines and coordinating their break times to maximize the efficiency of machine cells. Maintenance Technicians (MT) are responsible for implementing machine preventive maintenance and emergency maintenance procedures. MTs not only follow the maintenance schedule but also make decisions for engaging preventive maintenance in time to reduce machine break downs. There may be another type of intelligent agent, job releaser or shop floor controller. Their task is to monitor WIP (work in process) and avoid congestion while ensuring an adequate workload within a simulated manufacturing system.

While including intelligent agents in a simulation environment, the environment has to collect shop floor information. This information includes WIP; the status of the machine, part, and worker; and timing of preventive maintenance for intelligent agents before they make decisions. A structure of black boards for current floor shop knowledge needs to be provided for intelligent agents. Three types of intelligent agents, production operator, maintenance technician, and job releaser, will access this structure each time before making their next movements. However, each agent is in charge of his tasks locally, not globally. In other words, operation personnel only keep track of shop floor information in their working unit, a machine cell. Getting global shop floor information in a very short time is not practical since there is still a distance between different working units. Therefore, a reasonable knowledge domain for an intelligent agent is a machine cell.

Chapter 2. Problem Statement

In TMSSS, a machine centered approach to modeling is typical. Often this model format ignores or greatly simplifies intelligent decision making activities in the system of interest. It is certainly arguable that a complex manufacturing system's performance is effected by operating decisions which are made through the application of system knowledge and intelligence. Although some simulation packages include constructs to support decision making activities, the structure in which these constructs are implemented and decision making is supported results in the distribution of intelligence throughout a simulation model, neither an intuitive nor accurate representation. As Spier and Kempf (1995) state: "Current discrete event simulations of manufacturing are equipment-centered and can be run without any modeling of floor personnel since the equipment models include decision making capability. This is obviously not an accurate reflection of the manner in which current manufacturing systems operate. What is needed is a simulation that includes both equipment and personnel, and includes them with accurate emphasis....the details of human behavior are as important as the details of machine behavior to factory performance." Simply put, the research problem of interest is to address these shortcomings in current simulation architectures. We will extend an existing object oriented simulation environment to allow for the general representation of intelligent agents in manufacturing system simulation models. Note that we refer to intelligent decision making entities as "intelligent agents" because they are modular implementations of decision making applicable to very narrow domains. Examples of such intelligent agents are production operators and maintenance technicians, where their represented intelligence deals solely with responding to tasks based on defined policies and current system status.

Chapter 3. Background

Beaumariage (1990) has developed an object oriented modeling architecture (OOMA) to simulate manufacturing systems. He used object oriented concepts to create several basic manufacturing objects such as creator, queue, machine, and routing. Events generated by those basic objects are scheduled through an event calendar. Since the OOMA was written in an object oriented language (Smalltalk / V), it has great flexibility for extension to material handling and other features.

Beaumariage and Wang (1995) developed an object oriented architecture for the simulation of AGVs (automated guided vehicles) by extending the OOMA's material handling system. The AGV system consists of control points, track segments, and AGVs, along with an overall AGV-system-controller. In addition, the original machine structure of OOMA has been extended by including a server station with input and output queues as a platform for loading and unloading entities for AGVs. Control points are for the intersections of track segments, and server stations are attached to control points. AGVs can transport parts between server stations through track segments.

Except for the above concepts addressed by AGVS and OOMA, there are still a few indispensable characteristics for simulating manufacturing factories. For instance, machines require production operators' attention of when and how they serve parts. At this point, machine policies and job priorities become important. In addition, status of WIP limited by shop floor area needs to be controlled in order to maintain manufacturing efficiency. Using C++ programming, Spier and Kempf (1995) have simulated a simple semi-conductor factory integrating intelligent agents that operate machines following different manufacturing policies and priorities. Their purpose is to find the impact on simulated results when intelligent agents apply different policies and priorities. However, their approach lacks flexibility to change system configurations.

Basnet and Mize (1995) introduced a decision making framework, an expert system operating a flexible manufacturing system (FMS) created in Smalltalk-80. The FMS uses AGVs to transport parts between machines configured with input and output buffers and possible failures. A releaser controls WIP in the FMS by using different heuristic rules. Since machine buffers have limited space, the main duty of the releaser is to avoid congestion within the FMS to increase system efficiency. The FMS control emphasizes operation of the releaser, it does not define AGV structure in detail.

ProModel (Release 2, 1995), a simulation tool for manufacturing systems, allows for the representation of decision making functions. It can simulate manufacturing operators' actions and job priority selections. In ProModel, production manufacturing operators act as moving process initiators on defined network paths. Job priority selection rules are defined for each server. Manufacturing operators in ProModel are called 'resources', because they are merely job initiators. Although machine policy rules are specified in each manufacturing operator, when a manufacturing operator approaches a location, he has to refer to the job priority selection rule in the location before beginning processing of a job. Therefore, the machine priority rules are defined with respect to operators and job priority rules are separately defined with respect to each machine location. Note how this distributes decision making intelligence among multiple constructs in the simulation environment rather than creating an entity containing the appropriate decision making elements. ProModel fails to describe maintenance technicians' preventive maintenance and emergency maintenance activities which is essential in a manufacturing model. There is no representation of the finite capacity of the maintenance resource nor the interaction of this finite capacity with emergency and preventative maintenance tasks.

Nadoli and Biegel (1991, 1993) introduced blackboard systems into manufacturing intelligent agent simulation. They created a simulation environment, Intelligent Manufacturing Simulation Agent Tool (IMSAT), adopting blackboard concepts. Separate blackboard systems provide different information for intelligent agents with different tasks. Each knowledge base (blackboard system) contains only the information needed by associated intelligent agents. In other words, each type of intelligent agent had their own blackboard systems differing from others. In addition, each one carried a set of knowledge rules. IMSAT's architecture, developed in a Symbolics Lisp machine, consists of four main structures, intelligent agent description, hierarchical structure specification, product-flow definition and abstraction-mechanism specification, and simulation management. The above structures supported basic elements to simulate object oriented intelligent agents and allowed further extensions. However, their intelligent agent simulation mainly focused on the decision making of higher levels, such as the transactions of material acquisition, inventory control, production planning and control, and management. Our goal will be to concentrate on the interactions at the shop floor.

Adorni and Poggi (1993) published their views of implementing distributed artificial intelligence through an object oriented language, Actor-based Concurrent Distributed Language (ABCDL). They understood that distributed artificial intelligence was a good means to solve complicated problems. The nature of distributed artificial intelligence was to decentralize the original problem into many different modules, then define intelligent agents to coordinate among those modules and solve the original problem. They used three different entities, a sequential actor, a channel manager, and a distributed actor from ABCDL to illustrate distributed artificial intelligence concepts.

ABCDL was applied to define a DAI planning system called PROMETHEUS car navigation system. By computing the input message and referring its knowledge base, ABCDL combines sets of procedures and interacts results of those sets to return the best driving route. The point is that their work demonstrated the concept and methodology of object oriented language applying distributed artificial intelligence.

Chapter 4. Goals and Specific Objectives

Toward combining the above concepts relating to intelligent agent designs, this research develops a manufacturing simulation environment integrating intelligent agents allowing more flexibility to perform manufacturing systems simulation with intelligent decision making. To reach this goal, we start with the basic platform provided by Beaumariage and Wang's OOMA, which was written in an object oriented programming fashion. We extend the current OOMA to result in an intelligent agent simulation environment (IASE). IASE is flexible enough to simulate intelligent agents as in Spier and Kempf's implementation, and cover the function of a job releaser as addressed by Basnet and Mize. In addition, IASE adopts the concept of blackboard systems provided by Nadoli and Biegel.

Since constructing an IASE architecture is complex, we decide to solve it by using the concepts of Distributed Artificial Intelligence (DAI). By applying DAI, we will first decompose the problem into many sub-problems and tackle each sub-problem locally (Ginsberg, 1987). Then, defining intelligent agent objects among sub-problems provides problem solving algorithms. To implement the above DAI concept on intelligent agent simulation, we found that the object oriented programming is an appropriate approach.

To construct the IASE architecture by applying DAI, we need to decompose the original problem of simulating decision making IAs (IASE) in manufacturing systems by answering the following questions: What physical characteristics do IAs have? What types of IAs does IASE have? What decisions do IAs make? What system elements are necessary for simulating IAs? What knowledge do IAs have? What are the interactions between IAs? If we attack the above sub-problems explicitly, then the original problem can be solved.

To answer the first sub-problem, 'what physical characteristics do IAs have?', we will consider the IAs' dedicated zones, skills, and movement. Each IA should have a working area called zone where an IA is responsible for the machine cells in the zone. A zone may be totally or partially overlapping with different IAs. Facing varying types of machines, a MT's technical domains may not cover all types of machines in the shop floor. Normally, several

MTs are needed to tackle different types of machines in a system. Therefore, the technical skill characteristic is necessary for defining a MT. Since the number of machine cells is normally larger than the number of IAs, IAs have to travel around the shop floor to serve machines, which is time-consuming. IASE must provide for the representation of IA movement.

To answer the second sub-problem, 'what types of IAs does IASE have?', we conclude three types of intelligent agents, production operators (PO), maintenance technicians (MT), and job releasers (JR) performing different decision making tasks. POs make decisions (executing machine policies and deciding job priorities) within dedicated machine cells composed of several machines. MTs respond to machine break downs and conduct preventive maintenance within dedicated machine types. The JR, like a shop floor WIP monitor, controls job releasing of input stations. During congestion of the shop floor, the JR makes decisions to hold off parts coming into the system and decides when to release parts again.

To answer the third sub-problem, 'what decisions do IAs make?', we will focus on two domains to perform intelligent agent (IA) decision making functions. The first domain emphasizes machine policies. IASE provides machine policies for IAs to follow when more than one machine needs an IA's attention. For instance, POs determine the sequence to load/unload particular machines, and MTs pursue machine maintenance based on a given policy. The second domain is job priorities. When a PO is batching a machine, it needs to choose priority parts from available parts waiting in machine input queues to increase local machine cell efficiency. JR's task is controlling the release of jobs by limiting shop floor congestion.

To answer the fourth sub-problem, 'What system elements are necessary for simulating IAs?', we need to define the system environment to support IAs. In fact, this question is an extension of IA movement characteristic. The structure of machine cells and a global shop floor map specified with the position relationship of each machine cell are essential elements to simulate IAs. In addition, a knowledge base called policy and priority rule base is required. The rule base contains the working procedures of each policy and priority rules for IAs to follow while making decisions.

To answer the fifth sub-problem, 'What knowledge do IAs have?', we will focus on the responsibilities of each IA type to define their knowledge. If an IA is currently in charge of a zone (a group of machine cells), it is not likely to possess the newest knowledge other than the zone which is his responsibility. An IA with constantly and globally updated shop floor knowledge may be beneficial to the result of manufacturing system simulations. However, it is not representative of typical manufacturing situations.

In answering the final sub-problem, 'What are the interactions between IAs?', the immediate concern is the communication between IAs with the same job responsibility. Since each IA is the representation of a human worker, not a robot, they have to coordinate their working, training, and meeting hours with each other. They do not need to transfer shop floor information because this information can be obtained from the knowledge base.

Chapter 5. Methodology

The OOMA (Beaumariage, 1990) environment contains a primary manufacturing simulation platform and basic representations of static entities, but material handling features were not included. In 1995, Beaumariage and Wang developed AGV Simulation System (AGVSS) extending a material handler, AGV, inside of OOMA to represent a dynamic entity in a manufacturing simulation environment. In Figure 5.1, the physical structure and components of an AGV system are shown. AGVSS describes AGVs traveling around control points through track segments. Control points represent the connections between track segments, machine cells, part input and output stations. Machine cells in AGVSS contain machines with the same type. Each machine can only process one part at a time. Activities of the manufacturing system and AGVs are defined clearly in that system.

To actualize intelligent agent simulations, IASE uses the AGVSS as a platform to append reusable intelligent agent structures that include production operator, maintenance

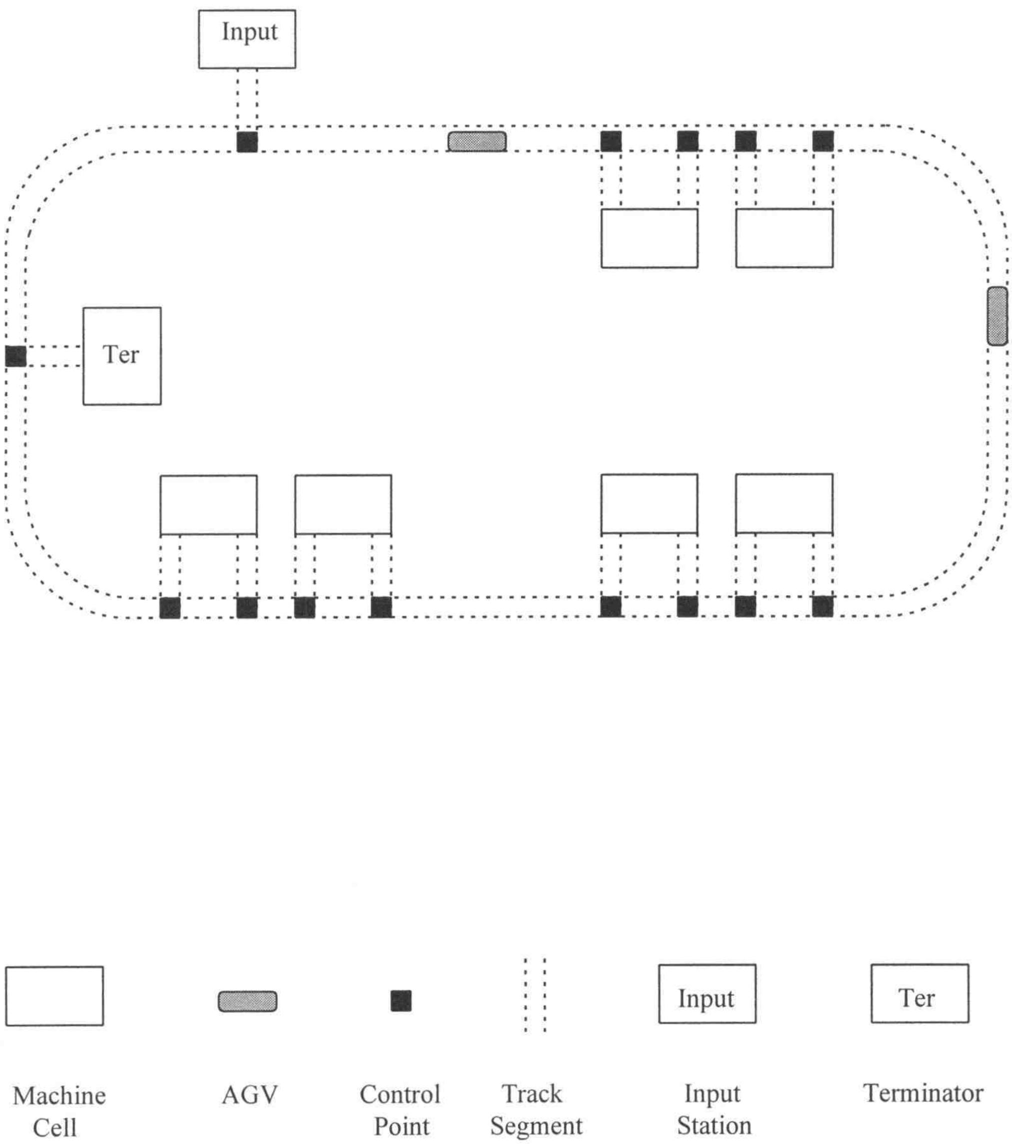


Figure 5.1 AGV Simulation System Structure and Components

technician, and job releaser. Besides, IASE also improves the original machine cell structure to a cell accommodating different types of machines. Each machine features a batching system accepting multiple batch formats. In IASE, IAs travel through the shop floor following paths between machine cells. The physical structure and components of IASE are shown in Figure 5.2.

5.1 Conceptual Architecture

Designed within an existing environment, this architecture builds on the already existing structures to realize the research goal. After decomposing the IASE structure using DAI, the following components are necessary to create IASE using OOPLs.

1) machine cell structure

2) production operator

3) maintenance technician

4) job releaser

5) shop floor map

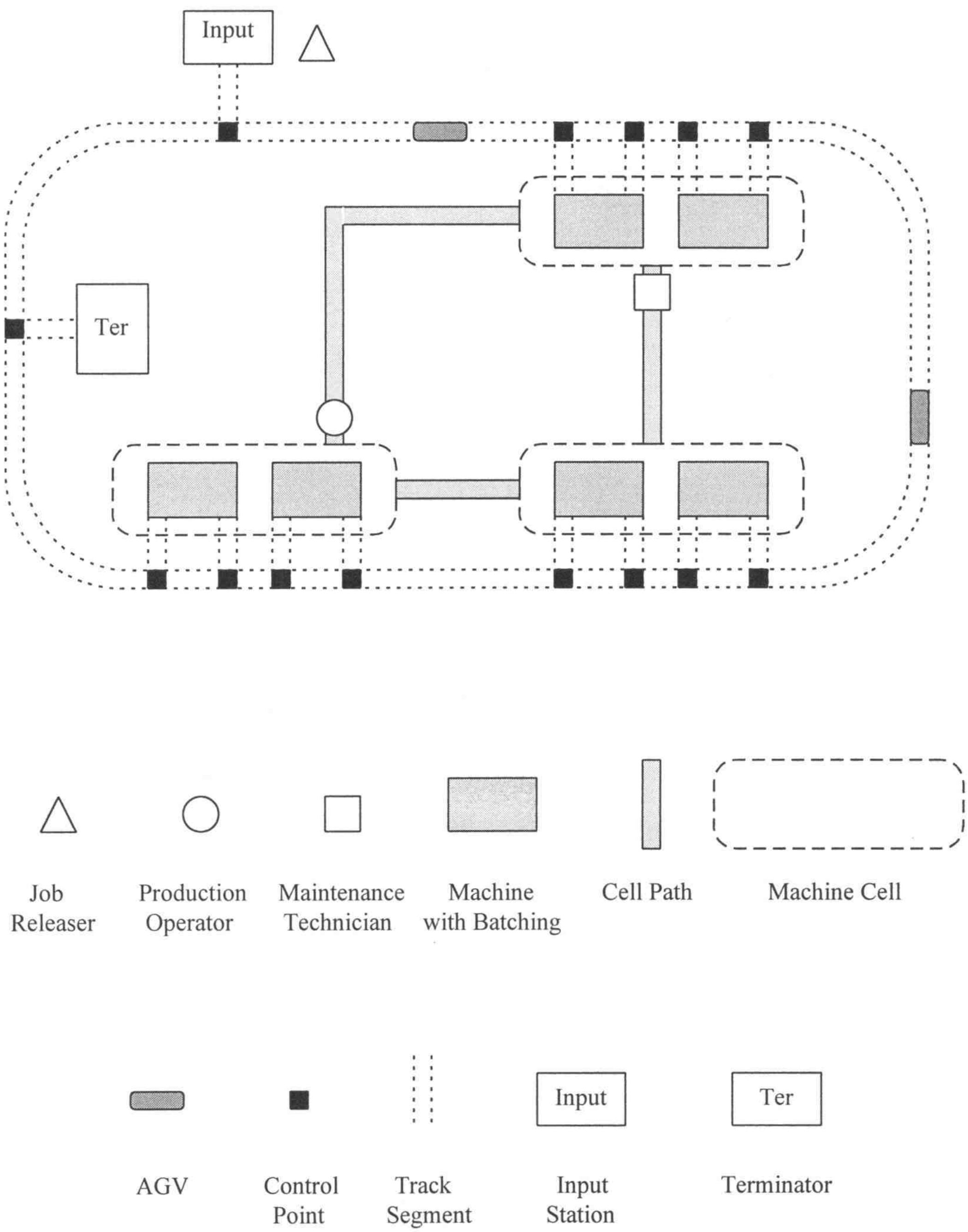


Figure 5.2 Structure of Intelligent Agent Simulation Environment Integrating AGV Simulation System

6) blackboard structure

7) batch structure and batching process

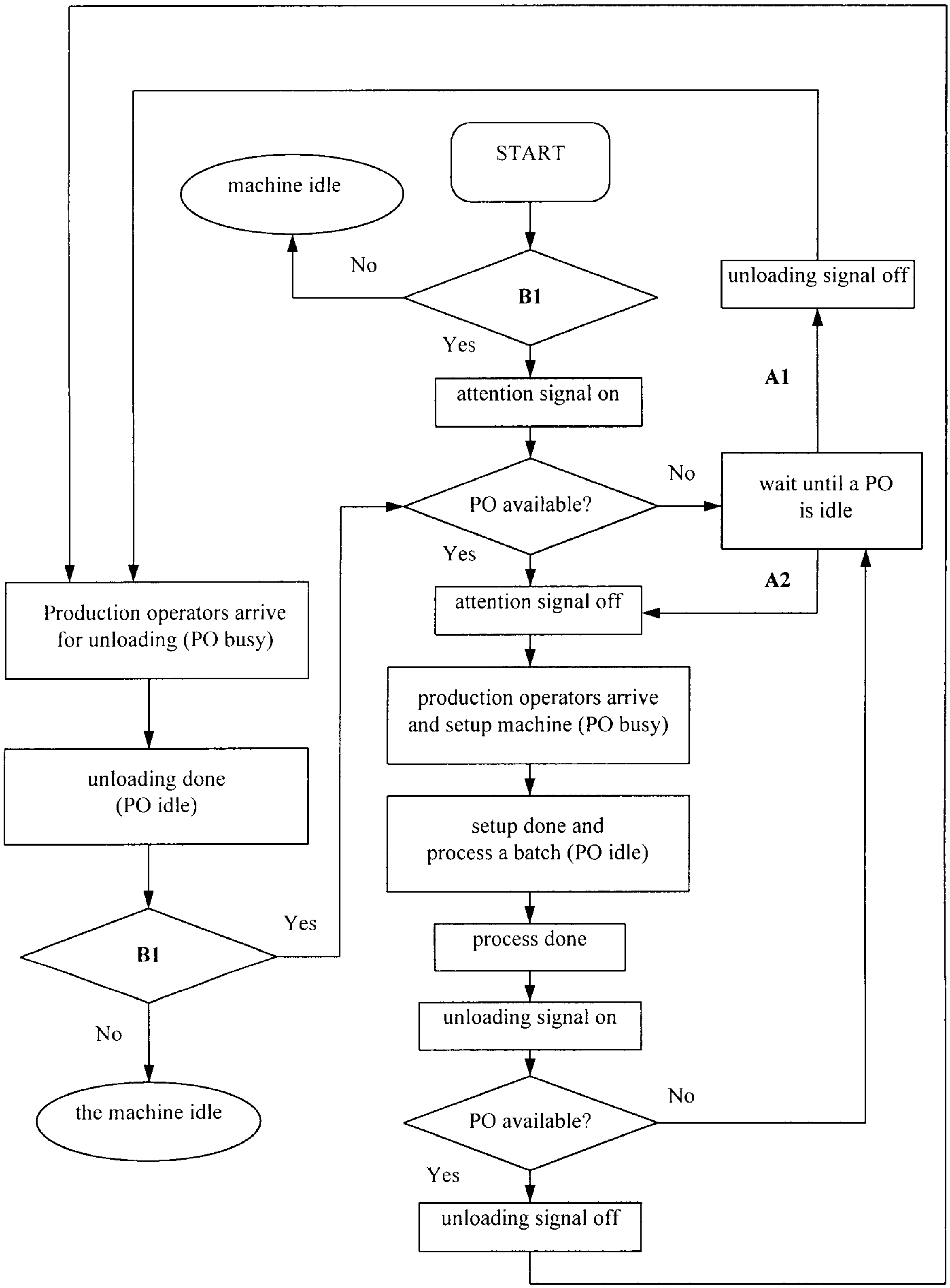
8) knowledge base for machine policies, job priorities, and decision rules.

5.2 Machine Cell Structure

The primary goal of a machine cell is to group machines together as a manufacturing unit to process parts efficiently. As a result, the IASE machine cell structure enables the grouping of different machines in a cell. However, different types of machines cannot serve the same parts at the same time. For IAs, each machine cell represents a working area. Within a machine cell, an IA does not need time to move from one machine to another. In other words, machine cells represent serving stops in a manufacturing shop floor for IAs.

5.3 Machine with Input and Output Queue

The structure of a machine in IASE includes both an input and an output queue. Figure 5.3 depicts the activity described in this section. When an AGV transports a part to



A1 = a PO responds to an unloading job
A2 = a PO responds to a loading job
B1 = if the machine is available and there are enough parts for batching

Figure 5.3 Flow Chart of Machine Queuing Process

a machine, the part first reaches the input queue. If there are enough parts in the input queue to form a batch, the machine's attention signal will be on and it posts a loading service request to the blackboard structure. The active attention signal is to call for an available PO. If all POs are busy, the loading service request will remain in the blackboard structure until a PO is available to load the machine. When the PO is ready for loading a machine, it will select priority parts based on an appropriate job priority rule to batch into the machine and start a process.

After a batch of parts is completed, the machine will set on an unloading signal and post an unloading request to the blackboard structure simultaneously. The unloading signal flags the machine as available for unloading. The unloading request posted to the blackboard structure acts as a reminder for the first available PO to serve the machine unloading job. A machine will not be available until the unloading process is finished. Those unloaded parts are put in the output queue while waiting for material handlers. If the output queue has no space for unloading parts, the batch of finished parts will block the machine until the output queue has enough space to accommodate the parts in the finished batch. As a consequence, if a machine is blocked because of a full output queue, the machine unloading signal will not be turned on, and an unloading request will not be posted.

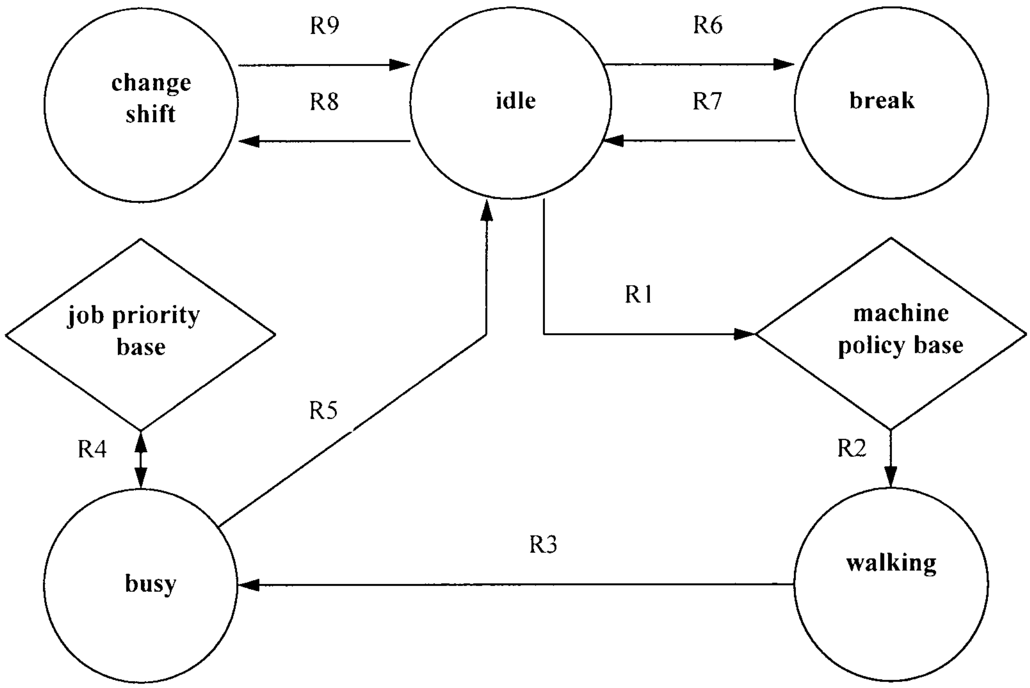
In a machine, the break down signal corresponds to machine break downs. The break down signal is turned on when the associated machine needs emergency maintenance. During a machine break down period, the input queue still accepts new parts but the attention signal will not function. As a result, no loading process occurs during a machine break down period. If a machine break down takes place after a PO heads to the machine for loading, the loading job will not be attempted once the PO finds out that the break down signal is on. As for those parts currently processing in the machine, the process will be interrupted and an appropriate part disposition is performed (see Maintenance Technician section for details). However, those batches of parts that have finished processing are not impacted by a machine break down. A PO can still unload those parts.

5.4 Production Operator

Traveling around the shop floor by way of cell paths, production operators respond to machine loading and unloading requests from different machine cells. The states and transitions for a PO are depicted in Figure 5.4. Based on the user given job priority rule, a production operator refers to a set of working procedures associated with the selected job priority rule in the knowledge base to determine which process request to service.

In the input queue, the parts to form a potential batch may be different from the parts actually selected by production operators (based on given job priority rule). A machine's input queue and corresponding attention signal only indicates that there are enough parts to form a batch. However, the part selection process (batching) is totally up to a production operator's operating policy.

When two or more production operators are available to serve a loading or unloading job, the production operator who is closest to the machine's location will respond to the job. Once two or more PO tie each other in terms of distance to serve a machine, the PO with lowest utilization will take



R1: called by the Blackboard structure.
R2: a target machine is found.
R3: arrive at the target machine.
R4: start a batching process (for batching).
R5: finish the service (loading or unloading).
R6: if 1) no machine needs the service ,
2) there is another PO available,
3) the PO has been working long enough.
R7: break time end.
R8: finish a shift.
R9: resume a new shift.

Rule Priority

idle State: R8 > R1 > R6

Assumptions

no preemption in walking, busy or break status

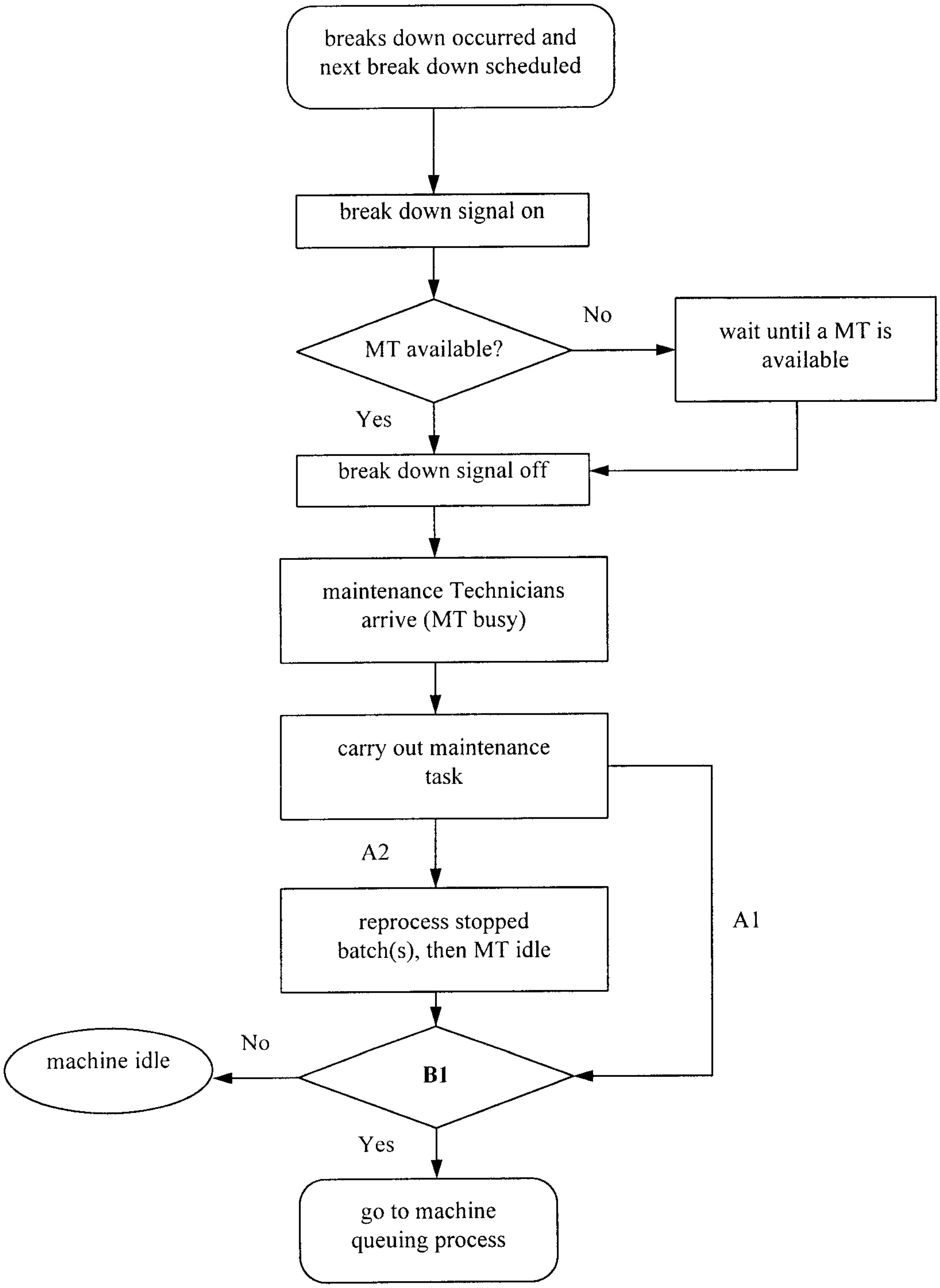
Figure 5.4 Production Operator State Transition Chart

the request. If a machine breaks down when a production operator arrives, an intended loading job will be canceled but an unloading job will still be attempted.

5.5 Maintenance Technician

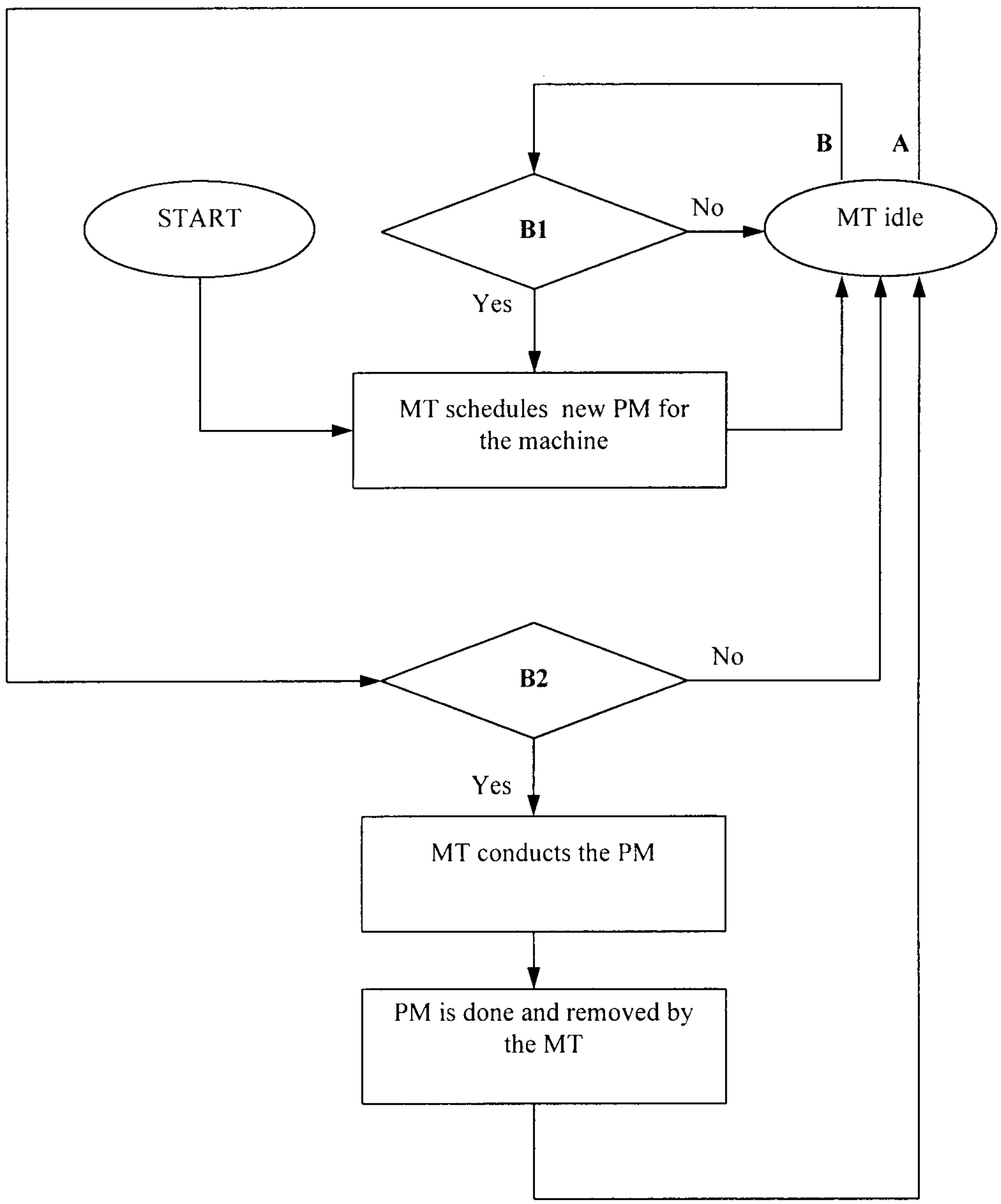
Maintenance Technicians (MTs) respond to two types of maintenance jobs; emergency maintenance and preventive maintenance. Emergency maintenance (EM) deals with machine break downs. The flow chart of EM actions is shown in Figure 5.5. When a machine breaks down, its break down signal will be on and it posts a repair request to the blackboard structure. If at least one MT is available, the MT closest to the machine will directly respond to the down machine. Otherwise, the blackboard structure holds the EM request until a MT is available.

Preventive maintenance (PM) is performed based on the MTs' scheduled machine lists, machines' PM lengths and PM intervals. A MT will create a PM schedule for machines based on the following logic (also see Figure 5.6); a MT will make a PM schedule for machines that it is responsible for according to each machine's maintenance interval. The MT



A1 = machine has 'part discarded' disposition
A2 = machine has 'reprocess' or 'process remaining time' disposition
B1 = if the machine is available and there are enough parts for batching

Figure 5.5 Flow Chart of Machine Emergency Maintenance



A = time to serve a machine's scheduled PM.
B = a controlled machine without the next PM schedule is found.
(A has higher priority than B)
B1 = if the machine is available without a scheduled PM.
B2 = if the machine is available and is not down.

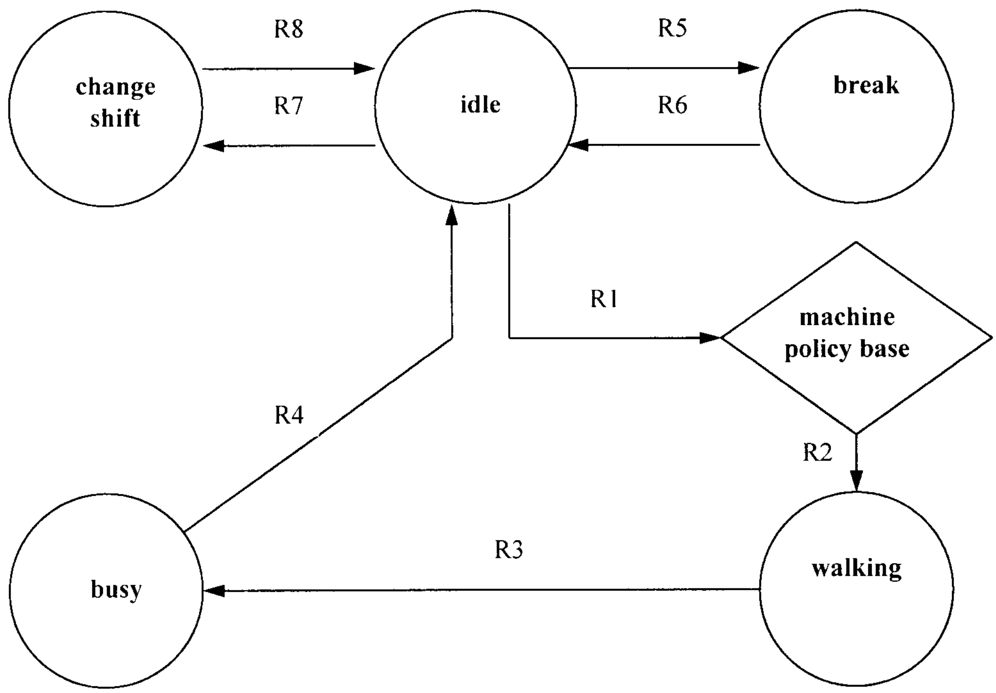
Figure 5.6 Flow Chart of Maintenance Technicians Preventive Maintenance

will serve a machine based on the machine's next PM time. Once a MT has performed a machine PM, the machine's next PM time is set based on the current time and the PM interval. If a machine's PM is post due, then the PM will be taken once a MT is available. If a machine breaks down and a scheduled PM is attempted, the scheduled PM will be canceled. The assumption for machine PMs is that a PM will be taken by a MT only if the target machine and a MT are idle. MT state transitions are shown in Figure 5.7.

When an EM has taken place, machines have three disposition options toward those parts still being processed. The options are Reprocess, Process Remaining Time, or Part Discarded.

5.5.1 Reprocess:

MTs will pull those parts out of the machine and reprocess them without further setup after the EM has been finished. Reprocessed parts will be treated like new parts in terms of processing time.



R1: called by the Blackboard structure.
R2: a target machine is found.
R3: arrive at the target machine.
R4: finish the service.
R5: if 1) no machine needs the service,
2) there is another MT available,
3) the MT has been working long enough.
R6: break time end.
R7: finish a shift.
R8: resume a new shift.

Rule Priority

idle State: R7 > R1 > R5

Assumptions

no preemption in walking, busy or break status

Figure 5.7 Maintenance Technician State Transition Chart

5.5.2 Process Remaining Time:

MTs will remove those parts from the break down machine and reprocess them with remaining time after an EM has been completed. For instance, assume a machine started to process a batch of parts at time 100 and will need 50 time units to process the batch (the batch should be done at time 150). At time 120, an EM occurred and the EM finished at time 140. In this case, the machine would continue processing the batch of parts at time 140 and end at time 170. The remaining time calculations for those blocked batches during a process are:

PT = Processing Time

EBT = Emergency Break Down Time

ST = the Starting Time of the Process

Remaining Processing Time = PT - (EBT - ST)

5.5.3 Part Discarded:

In this option, a MT will discard all the parts in a machine when an EM takes place. After the machine is done with the EM, the machine will accept parts from the input queue again. If there are parts available to form batches, the machine will post serving requests to the blackboard structure and wait for a PO loading service.

5.6 Job Releaser

There is only one job releaser (JR) on a shop floor. A JR acts as a controller for job arrivals to the system to avoid congestion on the shop floor. In other words, a JR is to avoid a job overload situation. In practical cases, a shop floor always has limited space for queuing parts. It is not reasonable to assume limitless storage space. Besides, a manufacturing system may need someone (a decision maker) to monitor each machine's utilization and queue length in the case of queuing overload or high utilization.

The simulation modeler is responsible for giving specified limit values in terms of machine utilization or queue length to each machine they want to monitor. The JR limits job creation if any monitored machine's utilization or queue length is over the associated limit.

5.7 Shop Floor Map

Manufacturing intelligent agents are constantly serving different machines that are not in the same location because the quantity of machines is usually larger than the number of IAs. That means IAs, POs and MTs will be traveling around the shop floor all the time. As a result, IAs have to know how to go from one machine cell to another machine cell. Including the shop floor information in each moving IA might be reasonable. However, it is more reasonable to create one general shop floor information source for moving IAs to share geographical information.

To construct such a shop floor map, cell paths between machine cells need to be defined in a form of travel time. Then, those defined cell paths are grouped together to form a shop floor map. The shop floor map structure provides IAs with the shortest path (distance) between two machine cells within a system. This follows the assumption that an IA would choose the shortest path for any movement.

5.8 BlackBoard Structure

The blackboard structure is used to provide IAs with current shop floor information. Like the eyes of IAs, the blackboard structure acts as a global shop floor monitor recording the status of each machine. For instance, when IAs make decisions, they can request desired shop floor information from the blackboard structure by specifying certain machine information items. It is important that the blackboard structure provides fresh shop floor information so that IAs can make sensible decisions.

Another important feature provided by the blackboard structure is that it provides a loading, unloading, and EM jobs registration center. When the blackboard accepts jobs requests from machines and no IA can immediately respond to those requests, the blackboard structure stores the requests in a list. Once a PO or MT gets idle, it checks the blackboard structure to see if there is any job registered in the blackboard structure for which they are responsible. If there is, then an idle IA will take the job request, execute the job, and delete the registered job from the blackboard structure. When the blackboard structure is sent an attention signal by a machine and there are IAs able to answer the job, the IA who is closest to the requesting machine will respond to the request. If there are two or more IAs tied in terms of distance, the IA with the lowest utilization will be chosen.

After a machine instance is removed from the blackboard load/unload request lists, the internal attention or unloading signal will be turned off only when the PO actually arrives at the machine and is ready to serve it.

5.9 Batch Structure and Batching process

A batch contains groups of parts (work flow items) with content that is based on user given batch formats. As a result, a batch structure has to contain the following information: batch format, batch content, and batch mark. Batch format represents legal part combinations to form a batch. Batch content keeps track of vacancies of a batch and those parts which have been loaded into a batch. Batch mark is a signal to identify whether a batch is available (filled up) for any valid batch format.

The batching process is an important capability for IA representation, particularly for production operators who perform job priority decision making. To activate batching processes, simulation modelers need to define batch formats for each machine type in advance. Production operators collect parts from input queues into machine batch(es) based on defined batch formats. If there are enough arriving parts to form any of the batches previously defined by users, the machine signals a loading message and registers a loading job request to the BlackBoard structure. Upon arrival, the PO, based on its designated job priority rule, selects currently available parts from the input queue for batching.

Before POs begin batching (loading) selected parts into machines, the parts in a machine's input queue have to go through a pre-select process. A pre-select process takes place when a PO first arrives at a requesting machine. Basically, a pre-select process is to let a PO know which parts will be batching into a machine at the end of the loading process. After the batching (loading) process is done, those pre-selected parts are loaded into the machine by a PO. The purpose of the pre-select process is to mark those parts which are going to batch into the machine so that other POs attempting another setup job at the same machine will not select parts that overlap with previous jobs. In both the batching and pre-selecting process, a PO will refer to the job priority rule base and execute the procedures associated with the PO's job priority rule specified previously.

5.10 Knowledge of Machine Policy, Job Priority Base, and Shop Floor Policy

The methods of machine policies, job priorities, and JR decision rules are defined within this structure. The structure contains many sets of procedures. Each set of procedures represents a machine policy, job priority, or decision rule. Once an IA confirms an instruction (machine policy, job priority, or decision rule) given by users, the IA will be directed to a knowledge base and execute a set of procedures associated with the given instruction.

Moving IAs (POs & MTs) need to refer to machine policy rules when there are two or more machines requesting service. The machine policy rules provided in IASE knowledge rule base are first in first out (FIFO), last in first out (LIFO), longest queue first (LQF), and random (RANDOM).

- FIFO: the first machine requesting service will get the first attention.
- LIFO: the last machine requesting service will get the first attention.
- LQF: the machine with longest queue length will get the first attention.

- RANDOM: an IA will serve requesting machines randomly.

Job priority rules are only for POs, since they are the IAs responsible for batching (selecting) jobs. The current job priority rules maintained by the knowledge rule base are first in first out (FIFO), last in first out (LIFO), priority part first (PPF), the oldest part in the system first (OPF), the least utilization in down stream machine first (DMU), and the least queue length in the down stream machine first (DMQ).

- FIFO: the first part in the queue head will get the first attention.
- LIFO: the first part in the queue tail will get the first attention.
- PPF: the specified part type with higher priority will get the first attention.
- OPF: the part having the longest time in the system will get the first attention.
- DMU: the part whose next destination machine (down stream machine) with the least utilization will get the first attention.

- DMQ: the part whose next destination machine (down stream machine) with the least queue length will get the first attention.

In executing the PPF rule, if there are tied priority values, the FIFO rule will be used to break ties.

Based on given decision rules, a job releaser refers to the knowledge base to get the procedures for monitoring shop floor machine performance. IASE provides two decision rules, machine queue and utilization monitoring policies, which combine with associated user input targets.

- queue: once the current machine input or output queue length exceeds the associated user input targets, the job releaser limits job creation.
- utilization: once the current machine utilization exceeds the associated user input targets, the job releaser limits job creation.

Job creation is no longer limited if the current queue length or utilization is lesser than the user input targets.

Chapter 6. Implementation

IASE follows the same fashion as OOMA and AGVSS that consists of a hierarchical class structure. In other words, IASE is able to create several class objects interacting with each other. Based on OOPL concepts, objects are created through the key words, class methods. As a result, using classes as receivers and key words as messages along with configuration arguments is the strategy to produce objects and enable reusability in IASE.

In the IASE implementation, there are two syntactic structures, object assignment statements and object initiator. Object assignment statements are used to generate new objects and establish dynamic bindings with other objects that have been already defined. An object assignment statement is composed of a target variable, an assignment operator, and an expression. A target variable represents a dynamic linkage to an object (defined by an expression) through the assignment operator.

An object initiator is used to initialize a new object or generate an action of a defined object. It mainly defines supporting elements in the IASE global environment for dynamically binding specific objects together based on the need. In terms of programming languages, an object initiator is merely an expression.

According to the above implementation methodologies, IASE's users need the knowledge of object oriented concepts, IASE object creating key words, and manufacturing shop floor layouts. However, understanding of the internal IASE structure is not required.

6.1 IASE Structure

The IASE structure is built under the environment of OOMA. Figure 6.1 shows the structure of IASE. SimObject is the root class of OOMA under Smalltalk environment's root class, Object. To inherit the capabilities existing in SimObject, IASE is constructed under the SimObject class. Within IASE, there are two types of object classes, intelligent agent simulation object classes (IASOC) and intelligent agent supporting element classes (IASEC). The function of IASOC emphasizes the concept of class SimObject, IASE is constructed under the SimObject class. reusability. For instance, a class in IASE required to

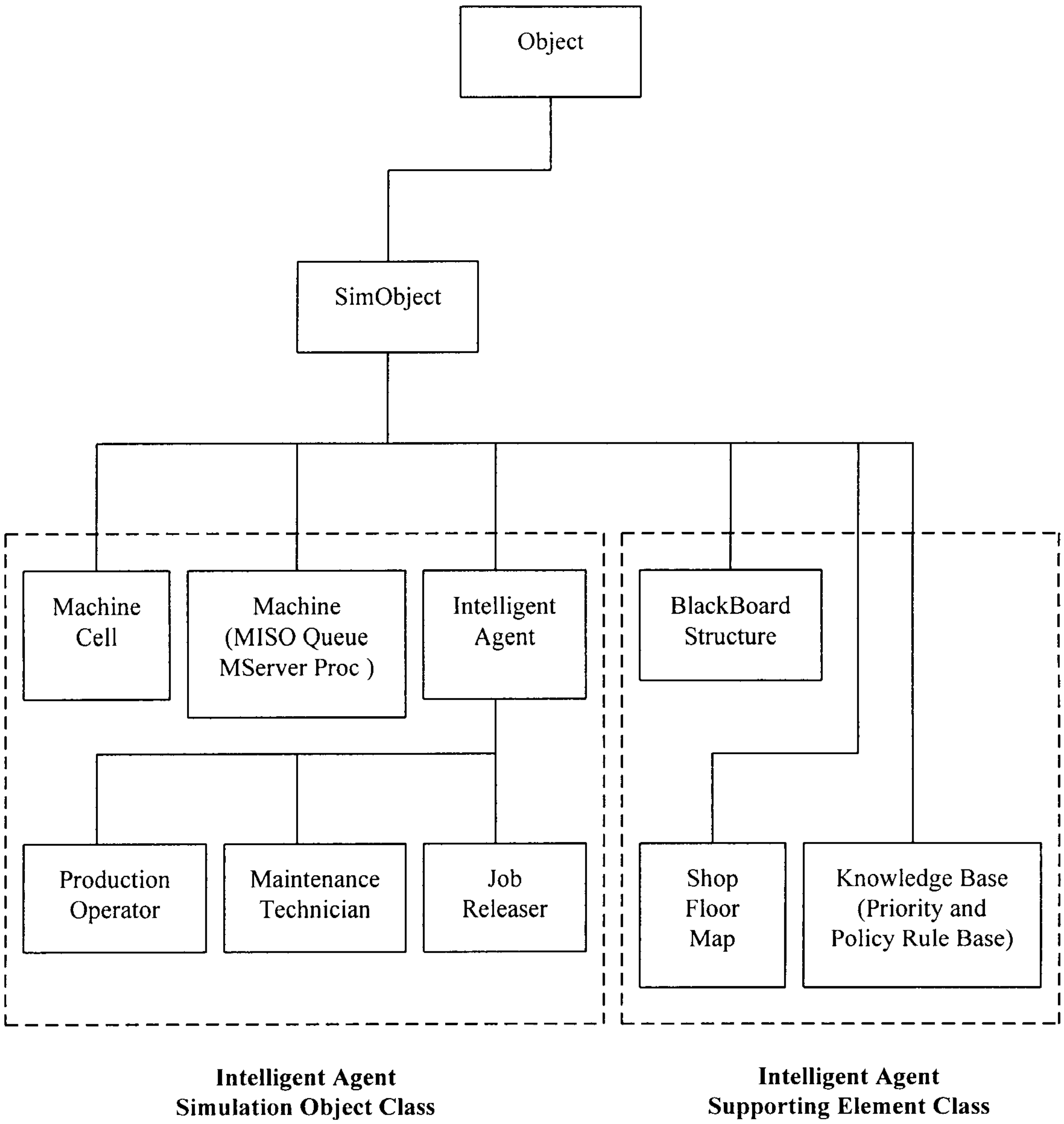


Figure 6.1 IASE Hierarchical Class Structure

create one or more instances in a model is categorized in IASOC, such as Intelligent Agent (Production Operator, Maintenance Technician, and Job Releaser), Machine, Batch, and so on.

IASEC is to support IASOC in IASE. At most only one object from IASEC exists in the system. Toward IASE, IASEC has two purposes, keeping track of global system information, and providing knowledge. The global system information center traces those objects generated by IASOC through global dynamic linkages, pointers. Dynamic linkages allow the information center to update the contents of traced objects once they get changes. The knowledge base is accessed by mobile smart objects, such as production operators, maintenance technicians, and job releasers. Smart objects make a decision that has been defined in the knowledge base.

6.1.1 Intelligent Agent Simulation Object Classes

The intelligent Agent class represents an abstract class to define the common characteristics of different types of IAs. Those characteristics include shift information, working statistics, and current location. This class avoids repeatedly defining instance variables among three types of IAs and lets its sub-classes directly inherit common information characteristics.

6.1.1.1 Intelligent Agent Instance Data Storage:

- intelligent agent's name
- current position
- current status
- shift information
- busy status

6.1.1.2 Intelligent Agent Instance Actions:

- change the status (idle, busy, or working) of an intelligent agent
- update the current location of an IA in terms of machine cells
- return an IA's name
- return an IA's location
- return an IA's status

- schedule a meeting or resting break for an IA (into event calendar)

When Production Operator class instances are created, they also are dynamically linked to the instance of BlackBoard Structure class. Production Operator class is one of the reusable classes in IASE because a system usually contains more than one PO. In IASE, the PO class is closely associated with Machine class, since a lot of actions provided by Machine class schedule calendar events that need to pass instances of the Production Operator class as arguments. As a result, if no PO instance is defined, machines in a system will be idle.

6.1.1.3 Production Operator Instance Data Storage:

- a list of machine cells controlled by a production operator
- machine policy rule name
- job priority rule name
- statistics of setup time (loading time)
- statistics of unloading time
- statistics of walking time

6.1.1.4 Production Operator Instance Actions:

- initialization of a production operator
- return IA's job priority rule
- return IA's machine policy rule
- return a list of controlled machine cells
- determine the control toward a machine cell
- check if any machine in the controlled machine list needs loading or unloading
- check if current time is appropriate to take a break
- print out the statistics for a production operator

Like the PO class having a reusable structure, Maintenance Technician class instances are also linked to the instance of the BlackBoard Structure class and constantly interact with Machine class instances. In addition, Maintenance Technician objects contain the preventive maintenance scheduling ability to schedule controlled machine preventive maintenance activities. To trigger the preventive maintenance scheduler, users have to initialize the key word in user implementation stage. Notice that at least one MT instance has to be defined if a system allows machine break downs during run time. Otherwise, the whole system may be blocked because of a machine break down.

6.1.1.5 Maintenance Technician Instance Data Storage:

- a list of machine cells controlled by a maintenance technician
- machine policy rule name
- statistics of maintenance time
- statistics of walking time
- a list of machines needing preventive maintenance
- next machine needing preventive maintenance
- the time for next preventive maintenance
- a list of machine names whose original PM schedules have been postponed

6.1.1.6 Maintenance Technician Instance Actions:

- initialization of a maintenance technician
- PM machine list
- return IA's machine policy rule
- return a list of controlled machine cells

- determine the control toward a machine cell
- check if any machine in the controlled machine list needs an EM or PM
- check if current time is appropriate to take a break
- print out the statistics for a maintenance technician
- append a machine and its PM interval onto a PM machine list
- return the PM of a specified machine in PM machine list

Although Job Releaser class has a reusable structure, one JR class instance is enough to represent in a system. Since the duty of a JR is to monitor machine status in the system, a JR instance will refer to the global information center every time a potential job can be issued. To implement JR, an instance of JR class will receive machine target values in the form of utilization and queue length. As a consequence, the JR can monitor system creators (input stations) so that job creations can be limited if any machine's utilization or queue length exceeds the target values.

6.1.1.7 Job Releaser Instance Data Storage:

- list of monitored machines' names
- list of machines' monitoring rule associated with monitored machine list
- list of limited values associated with monitoring rules list

6.1.1.8 Job Releaser Instance Actions:

- initialization of a job releaser
- add a machine into monitored machine list
- return the list of monitored machines' name
- return the list of machines' monitoring rule associated with monitored machine list
- return the list of limited values associated with monitoring rules list

Batch Class represents the batching formats and quantities information in Machine class instance. Batch class instances have to be initialized after the associated instance of Machine class has been created, because it is meaningless to solely define Batches without Machines. A batch contains one or more instances of Work Flow Item that represent parts. Besides, a batch comes with batch format information defined in the user implementation stage. Batch format information is represented by a collection of part names and quantities.

6.1.1.9 Batch Instance Data Storage:

- batch content
- batch format
- batch mark

6.1.1.10 Batch Instance Actions:

- create an instance of batch structure
- add a new batch format into a batch structure
- check if a batch structure is done with any kind of batch format
- clear all the parts in a batch
- mark the batch as a done batch
- remove the batch mark

- add select signals onto all the parts in the batch
- remove select signals from all the parts in the batch
- remove a routing from each part in the batch
- return batch content
- return batch format
- return batch mark
- obtain a setup (loading) time for the batch
- obtain a processing time for the batch
- obtain an unloading time for the batch
- return a part by specifying a batch position
- return a boolean message whether a part can fit in the batch
- return a combination of parts that matches one of the batch formats

A machine with a single input queue, single output queue and batch processing ability is represented by Machine Class. Machine class also has a reusable structure. Each of its instances couple with two instances of AGV Queue class.

Two sets of Batch class instances are also included in each Machine class. Two sets of Batch instances represent the potential batch check platform and the actual batch content within a Machine class instance. The number of batch instances in each set is determined by the number of the same type parallel servers that share an input and an output. Each completed machine class instance (with batches and queues) will be pointed to by an associated instance of Machine Cell.

6.1.1.11 Machine Instance Data Storage:

- machine name
- the number of the same type servers
- status and statistic information
- instances of Batch class
- resource claim for each parallel server
- attention signal
- unloading signal
- schedule signal
- machine status

- break down time interval
- EM length
- interarrival time between EMs
- next PM time

6.1.1.12 Machine Instance Actions:

- accept a new work flow item
- process a batch of work flow item
- complete processing a batch
- change machine status and statistic when interacting with IAs
- print out machine statistic information
- schedule machine break down
- execute PM

Machine Cell class is to define a zone for grouping Machine instances with the same geographic location together. When a machine cell is defined, a collection data structure will link to those Machine class instances with the same zone. As a result, the machine cell, an IA traveling points of Shop Floor Map can keep track of those instances of Machine class. Then each defined Machine Cell class instance will be pointed to by an instance of BlackBoard Structure Class.

6.1.1.13 Machine Cell Instance Data Storage :

- machine cell's name.
- a list of machines in the machine cell.

6.1.1.14 Machine Cell Instance Actions :

- return a specified machine's configurations and current physical information if the machine is in the machine cell.

6.1.2 Intelligent Agent Supporting Element Classes

Shop Floor Map Class represents the distances between machine cells in terms of time units. An instance of Shop Floor Map is adequate to describe a system shop floor. Basically its class instance contains a set of cell paths that specify distances between machine cells. To implement the Shop Floor Map, an object initiator syntax is used. The message part of the object initiator is a key word from Shop

Floor Map class methods. The key word passes arguments that contain instances of Cell Path Class.

6.1.2.1 Shop Floor Map Instance Data Storage:

- name of the shop floor map
- a collection of all defined cell paths

6.1.2.2 Shop Floor Map Instance Actions:

- add a cell path into the cell path collection
- add map name
- initialization of a shop floor map
- return shortest time based on two given machine cells (starting cell & destination cell)

Like the Shop Floor Map class, BlackBoard Structure class needs only one instance in an IASE model. That instance stores the information of shop floor machine cells and IAs. In other words, Machine Cell, Production Operator, and Maintenance Technician instances are dynamically linked to data collections in the BlackBoard Structure instance. As a result, if any of those linking objects changes its content, the information associated with that linking object in the BlackBoard Structure class instance will be updated.

The number of machine cell instances in the associated collection always remains the same during run time, but the number of instances in the collections pointing to PO and MT instances will be changed if there are POs or MTs taking breaks. What actually happens is that the instance of a PO or MT will be deleted if it is on a break. The deletion does not mean the deleted instance is gone. In fact, the instance will be attached with a calendar event that schedules IAs' break activities. Once the event associated with IA's finishing breaks is executed, the IA's instance will be linked back to the original data collection in the BlackBoard Structure instance.

In the BlackBoard Structure instance, there are other data collections storing Machine instances that need EM, loading, or unloading. These data collections keep track of those machines requesting IA services. For instance, if a machine needs loading service, the BlackBoard Structure instance will point to the Machine instance associated with the loading service request. After an IA finishes the loading service for that machine, the machine instance link in the BlackBoard Structure instance is removed. Otherwise the linkage remains in the collection until a PO responds to it.

6.1.2.3 BlackBoard Structure Instance Data Storage:

- list of input station(s)
- list of machine cells
- list of maintenance technicians
- list of production operators
- list of machines requesting loading jobs
- list of machines requesting unloading jobs
- list of machines requesting EM jobs

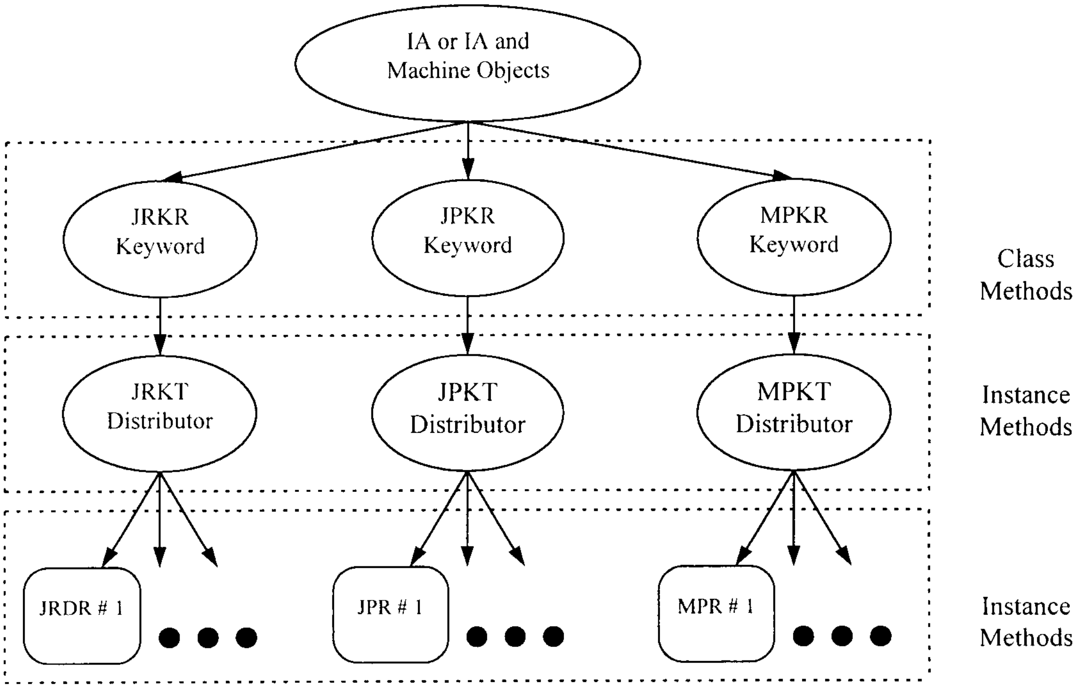
6.1.2.4 BlackBoard Structure Instance Actions:

- initialize a new BlackBoard structure
- add an input station into input station list
- add a production operator into PO list
- add a maintenance technician into MT list
- remove a production operator from PO list
- remove a maintenance technician from MT list

- add a machine requesting loading job into loading requesting machine list
- add a machine requesting unloading job into unloading requesting machine list
- add a machine requesting EM job into EM requesting machine list
- remove a machine loading job from loading requesting machine list
- remove a machine unloading job from unloading requesting machine list
- remove a machine EM job from EM requesting machine list
- retrieve MT list
- retrieve PO list
- retrieve EM requesting machine list
- retrieve loading requesting machine list
- retrieve unloading requesting machine list
- select a MT who is closest to a requesting machine
- select a PO who is closest to a requesting machine

The Machine Policy and Job Priority Knowledge Base Class (MPJKBC) is categorized as an abstract class that does not generate any instances but MPJKBC also contains no class and instance variable. The actual purpose of MPJKBC is to furnish a work place to implement machine policy and job priority rules. MPJKBC embeds machine policy, job priority and JR decision rules that are represented by the interactions of IASE class objects. In other words, MPJKBC carries sets of IA working procedures to implement machine policy and job priority rules. Each set of working procedures along with passing arguments, IA and/or machine object, is treated as a reusable manufacturing module.

In MPJKBC, there are three class methods separately assigned to machine policy, job priority, and job releaser decision rules for referring specific knowledge type (see Figure 6.2). Each class method acts as a keyword directing passing arguments, IA and/or machine objects to the knowledge type distributor represented by an associated MPJKBC instance method. Then, a knowledge type distributor based on an IA's given knowledge rules calls another instance method to physically execute machine policy, job priority, or JR decision rules. For instance, as an argument, a MT with machine policy rule FIFO is passed to the machine policy knowledge type distributor. The machine policy knowledge type distributor will identify the machine policy rule that the MT has. Since the MT is carrying FIFO rule, the machine policy knowledge distributor will execute another instance method describing MT FIFO machine policy rule, along with the MT instance.



JRKR/T => Job Releaser Knowledge Rule/Type

JPKR/T => Job Priority Knowledge Rule/Type

MPKR/T => Machine Policy Knowledge Rule/Type

JRDR => Job Releaser Decision Rule

JPR => Job Priority Rule

MPR => Machine Policy Rule

Figure 6.2 Machine Policy and Job Priority Knowledge Base Class Structure

Chapter 7. Validation/Verification and Case Studies

To verify IASE, the SLAM II Simulation Language (Pritsker, 1986) is used as a comparison vehicle since SLAM II has been widely applied in educational and industrial practice. If a scenario's result in SLAM II has no difference from the result generated by IASE, then we conclude that the IASE implementation is verified.

A case study describing a manufacturing system is modeled in both IASE and SLAM II environments. Each model is run 10 times and measures of performance are generated. Using hypothesis tests, statistics of the 10 runs from each environment are compared to show if two results have significant difference. Since it is impossible to compare every IASE feature to SLAM II model, a general case study is adopted to verify certain categories of system performance. However, because IASE is focusing on the simulation of intelligent agents, a separate case study involving three IA types is performed to demonstrate its IA simulation ability.

7.1 Case Study 1

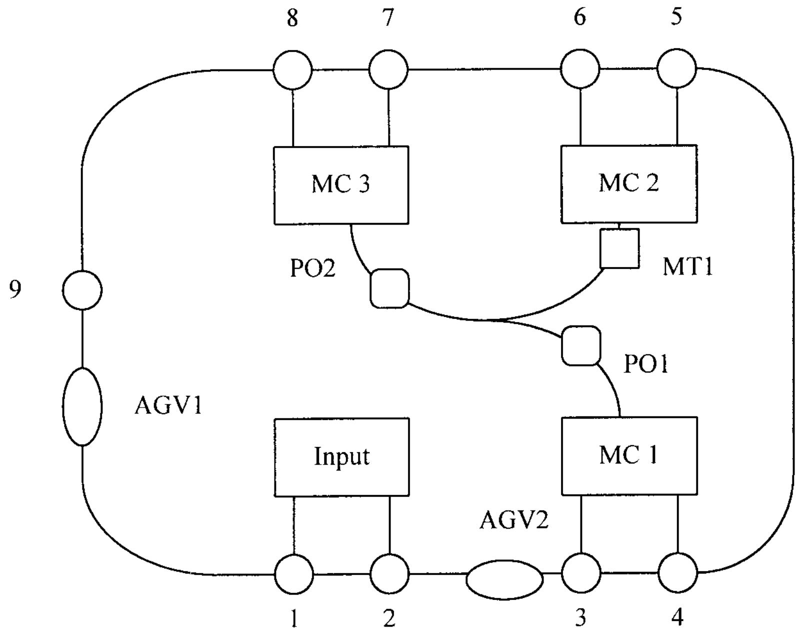
7.7.1 Problem Statement:

A manufacturing system processes part 1, 2, and 3. The interarrival times of part 1, 2, and 3 are normally distributed with means of 204, 336, and 3360 minutes per lot and standard deviations of 5, 3, and 3 minutes, respectively. Each part type must go through three machine types, A, B, and C, and in that order. Every machine type has the ability to batch three parts at a time in any combination of three parts. Each loading and unloading action needs the attention of a production operator. A maintenance technician is responsible for machine break downs. Table 1, 2, and 3 summarize the important system entity configurations. Figure 7.1 shows the graphical layout of this system.

Table 1

Case Study 1 Machine Configurations

Time unit: minute	Loading Time	Processing Time	Unloading Time	Break Down Interval
Machine A in Cell 1	20	Normal Distr. (225, 5)	40	
Machine B in Cell 2	15	Normal Distr. (85, 3)	15	Normal Distr. (2000, 20)
Machine B in Cell 3	10	Normal Distr. (105, 3)	10	



Input = system input station
MC 1 = machine cell 1
MC 2 = machine cell 2
MC 3 = machine cell 3
PO 1 = production operator 1
PO 2 = production operator 2
MT 1 = maintenance technician 1
AGV = automatic guided vehicle
1 = control point 1, and the input queue of input station
2 = control point 2, and the output queue of input station
3 = control point 3, and the input queue of machine cell 1
4 = control point 4, and the output queue of machine cell 1
5 = control point 5, and the input queue of machine cell 2
6 = control point 6, and the output queue of machine cell 2
7 = control point 7, and the input queue of machine cell 3
8 = control point 8, and the output queue of machine cell 3
9 = control point 9 and AGV staging area

Figure 7.1 System Layout of Case Study 1

Table 2

Case Study 1 Production Operator Configurations

	Cell Controlled	Current Location	Machine Policy	Job Priority
PO 1	1, 2	1	FIFO	FIFO
PO 2	2, 3	2	FIFO	FIFO

Table 3

Case Study 1 Maintenance Technician Configurations

	Machine Controlled	Current Location	Machine Policy	EM Length
MT 1	1, 2, 3	3	FIFO	240 min.

7.1.2 Assumption:

- travel time from one cell to another cell for IAs is 0
- if batches are interrupted by machine break downs, the batches will be reprocessed using remaining processing time
- each simulation run ends at time 100400 and the statistics are cleared at time 50000 when steady state is reached
- two AGVs are used to transport parts between machine cells

7.1.3 Test Procedure:

A hypothesis test with α=0.05 is conducted using 10 sample values from each simulation environment. The null hypothesis (*Ho*) assumes no difference between the simulation models (environments) and the alternate hypothesis (*Ha*) states there is significant difference between the two models (environments).

Null hypothesis: Ha: $\mu 1 = \mu 2$

Alternate hypothesis: Ho: $\mu 1 \neq \mu 2$

$\mu 1$ = a measurement result from IASE model

$\mu 2$ = a measurement result from SLAM II model

m = number of run in IASE model = 10

n = number of run in SLAM II model = 10

$\overline{X}$ = a measurement's mean of m runs from IASE model

$\overline{Y}$ = a measurement's mean of n runs from SLAM II model

S_1 = a measurement's standard deviation of m runs from IASE

S_2 = a measurement's standard deviation of n runs from SLAM

df = degree of freedom = $m + n - 2$

$$t = \frac{\overline{X} + \overline{Y}}{Sp\sqrt{\frac{1}{m} + \frac{1}{n}}} \qquad Sp = \frac{(m-1)S_1^2 + (n-1)S_2^2}{m+n-2}$$

If $|t| < t_{\frac{\alpha}{2},df}$, *Ho* is not rejected, where $t_{\frac{\alpha}{2},df} = t_{0.025,18} = 2.101$. Otherwise, *Ho* is rejected.

According to the calculations in Table 4, each tested measurement shows no significant difference between IASE and SLAM II results, because the absolute value of *t* from each test measurement is less than $t_{\frac{\alpha}{2},df} = t_{0.025,18} = 2.101$. Notice that a hypothesis test on the total observations in machine cell 2 is not performed. That is because the total part observations of machine cell 2 in IASE includes double counting of reprocessed batches caused by machine break downs, and SLAM II only counts batches that are finished by machine cell 2.

Since the case study involves AGVs that are poorly represented in the SLAM II model, hypothesis tests on some measurements are not performed. To avoid the differences caused by material handers in both models, the hypothesis tests focus on the utilization of each machine cell, PO, and MT, and the total parts finished in the system. The complete simulation models and results from both simulation environments are shown in Appendices A, B, C, and D.

Table 4

Case Study 1 Hypothesis Test Result

IASE Model

Number of Run	Mach. Cell 1		Mach. Cell 2		Mach. Cell 3		Final	PO 1	PO 2	PO 1+2	MT 1
	Obs.	Utlz	Obs.	Utlz	Obs.	Utlz	Output	Utlz	Utlz	Utlz	Utlz
1	138	0.6113	139	0.2337	137	0.2854	411	0.1504	0.1503	0.3007	0.1209
2	138	0.6145	143	0.2327	137	0.2849	411	0.1500	0.1503	0.3003	0.1210
3	138	0.6141	146	0.2337	137	0.2867	411	0.1502	0.1505	0.3007	0.1212
4	137	0.6142	142	0.2309	138	0.2853	414	0.1502	0.1449	0.2951	0.1238
5	138	0.6130	146	0.2343	138	0.2873	411	0.1508	0.1507	0.3015	0.1197
6	137	0.6119	145	0.2316	137	0.2866	411	0.1498	0.1494	0.2992	0.1213
7	137	0.6118	142	0.2313	136	0.2838	408	0.1500	0.1495	0.2995	0.1230
8	137	0.6117	145	0.2327	137	0.2844	411	0.1503	0.1499	0.3002	0.1238
9	138	0.6127	142	0.2308	137	0.2867	411	0.1501	0.1502	0.3003	0.1234
10	138	0.6150	140	0.2312	139	0.2873	417	0.1500	0.1505	0.3005	0.1226
Mean	137.6	0.6130	143	0.2325	137.3	0.2858	411.6	0.1502	0.1496	0.2998	0.1223
STD	0.5164	0.0013	2.4495	0.0015	0.8232	0.0012	2.3664	0.0003	0.0017	0.0018	0.0014

SLAM Model

Number of Run	Mach. Cell 1		Mach. Cell 2		Mach. Cell 3		Final	PO 1	PO 2	PO 1+2	MT 1
	Obs.	Utlz	Obs.	Utlz	Obs.	Utlz	Output	Utlz	Utlz	Utlz	Utlz
1	137	0.6150	138	0.2341	137	0.2881	411			0.2999	0.122
2	137	0.6161	138	0.2334	138	0.2877	414			0.3001	0.1214
3	137	0.6111	137	0.2305	137	0.2849	411			0.2994	0.1238
4	137	0.6162	138	0.2324	137	0.2854	411			0.2997	0.1212
5	138	0.6101	138	0.2333	137	0.2849	411			0.3010	0.1238
6	138	0.6131	138	0.2335	137	0.2852	411			0.3006	0.1238
7	138	0.6148	138	0.2308	137	0.2877	411			0.3010	0.1224
8	137	0.6122	137	0.2312	137	0.2847	411			0.2991	0.1207
9	137	0.6150	138	0.2330	138	0.2872	414			0.3001	0.1190
10	137	0.6119	137	0.2342	137	0.2870	411			0.2993	0.1220
Mean	137.3	0.6135	137.7	0.2326	137.2	0.2862	411.6			0.3000	0.1220
STD	0.4830	0.0021	0.4830	0.0013	0.4216	0.0013	1.2649			0.0006	0.0015

Sp	0.5	0.0018		0.0013	0.6540	0.0013	1.8974			0.0013	0.0015
t	1.3416	-0.6593		-0.5898	0.3419	-0.7512	0.0000			-0.3670	0.3596

7.2 Case Study 2

This case study is intended to demonstrate the IA representation ability of IASE. By extending the basic configuration from case study 1, case study 2 demonstrates the flexibility of configuring JR activities, various batching formats, routings, working shifts, and PM scheduling. The results of case study 2 are shown in Appendix E.

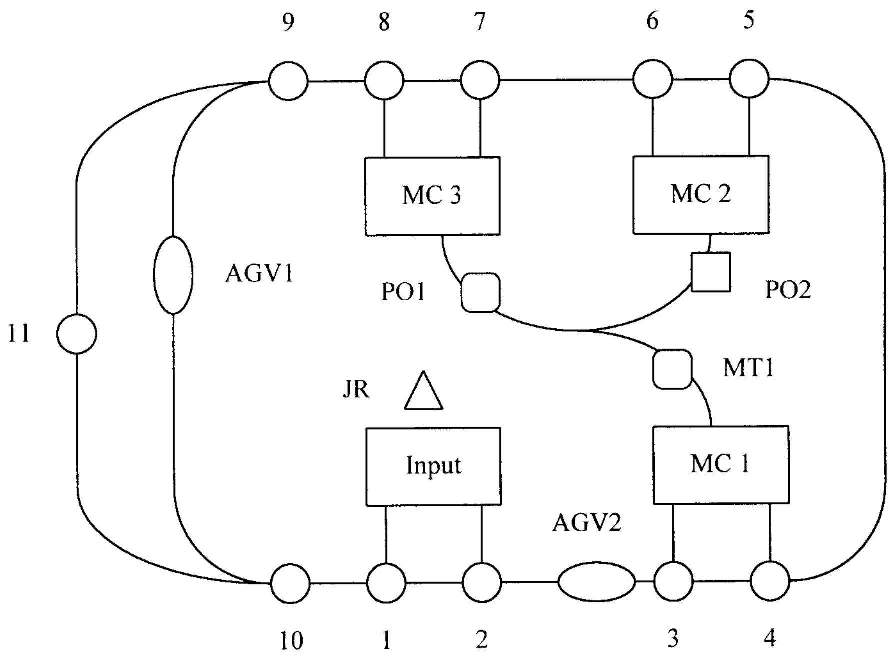
7.2.1 Problem Statement:

A semi-conductor factory produces types of wafer, A, B, and C. The production rates of wafer A, B, and C are 50, 30, and 3 lots per week respectively. There are three machine types, 1, 2, and 3, located in machine cells 1, 2, and 3, with six processing steps for producing wafers. Tables 5-11 contain system parameters, and Figure 7.2 illustrates the system layout.

Table 5

Case Study 2 Machine Configurations

Time unit: minute	Loading Time	Unloading Time	Break Down Interval	EM Length	Number of Machine
Machine 1 in Cell 1	20	40	-	-	2
Machine 2 in Cell 2	1 5	15	10080	840	2
Machine 3 in Cell 3	10	10	-	-	1



Input = system input station
MC 1 = machine cell 1
MC 2 = machine cell 2
MC 3 = machine cell 3
PO 1 = production operator 1
PO 2 = production operator 2
MT 1 = maintenance technician 1
JR = job releaser
AGV = automatic guided vehicle
1 = control point 1, and the input queue of input station
2 = control point 2, and the output queue of input station
3 = control point 3, and the input queue of machine cell 1
4 = control point 4, and the output queue of machine cell 1
5 = control point 5, and the input queue of machine cell 2
6 = control point 6, and the output queue of machine cell 2
7 = control point 7, and the input queue of machine cell 3
8 = control point 8, and the output queue of machine cell 3
9 = control point 9
10 = control point 10
11 = control point 11 and AGV staging area

Figure 7.2 System Layout of Case Study 2

Table 6

Case Study 2 Machine Batch Configurations

	Batch Format Specifications
Machine 1	Any combination of three parts except parts A, and B cannot mix and at most one part C in a batch
Machine 2	Any combination of three
Machine 3	A batch contains only parts with the same type

Table 7

Case Study 2 Wafer Routing

	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6
Wafer A part A	Machine Cell 1	Machine Cell 2	Machine Cell 3	Machine Cell 2	Machine Cell 1	Machine Cell 3
Wafer B part B	Machine Cell 1	Machine Cell 2	Machine Cell 3	Machine Cell 2	Machine Cell 1	Machine Cell 3
Wafer C part C	Machine Cell 1	Machine Cell 2	Machine Cell 3	-	-	Machine Cell 3
Process Time	225 min.	30 min.	55 min.	50 min.	255 min.	10 min.

Table 8

Case Study 2 Production Operator Configurations

	Cell Controlled	Initial Location	Machine Policy	Job Priority
PO 1	1, 2	Cell 1	LQF	OPF
PO 2	2, 3	Cell 2	LQF	OPF

Table 9

Case Study 2 Production Operator Shift Information

	Shift Length	Meeting Time	Break Time	Meeting Length	Break Length
PO 1	540	1	2	60 min.	60 min.
PO 2	540	1	2	60 min.	60 min.

Table 10

Case Study 2 Maintenance Technician Configurations

	Mach. Cntrl	Mach. Policy	Shift Length	Meeting /Shift	Break /Shift	Meeting Length	Break Length
MT 1	1,2,3	FIFO	600 min.	1	2	30 min.	45 min.

Table 11

Case Study 2 Machine Preventive Maintenance Schedule Configurations

	Interval Between PM	PM Length
Machine 1	1440 min.	75 min.
Machine 2	720 min.	120 min.
Machine 3	540 min.	30 min.

Table 12

Case Study 2 Job Releaser Configurations

	Standard Target Value	
	Utilization	Queue Length
Machine 1	60 %	-
Machine 2	-	20
Machine 3	-	20

7.2.2 IASE Simulation Model

In order to model the system in IASE, Figure 7.3 presents the simulation code for implementing necessary elements and objects. Several comment blocks in Figure 7.3 indicate separate sections that are explained in the following paragraphs.

Block 1 in the figure defines local variables to represent necessary IASE elements and objects.

Block 2 describes standard model specifications for AGVs. Please refer to AGVSS (Beaumariage and Wang, 1995).

Block 3 initializes a new BlackBoard structure. The variable, blackBoardStr points to an instance of the BlackBoard Structure that is constructed by a BlackBoard Structure Class receiver and a unary selector, initializeBlackBoard.

Blocks 4 and 5 define instances of input station and machines. Each variable is assigned to an associated instance created by the given message. Tables 13 and 14 describe the functions provided by keywords for the input station and machines. Then, machine instances are sent the 'addBatchFormat:' message along with arguments to define batch formats.

```
/***************************************************************************/
/*                                Block 1                                    */
/***************************************************************************/
|
p0 p1 p2 p3 p4 p5 p6 p7 p8 p9 p10 p11
s1 s2 s3 s4 s5 s6 s7 s8 s9 s10 s11 s12
agv1 agv2 machineA machine1 machine2 machine3
term agvSystem routing1 routing2 routing3 workOrder1 workOrder2 workOrder3
creater1 creater2 creater3 calendar
machCell1 machCell2 machCell3 blackBoardStr cp1 cp2 cp3 op1 op2 mt1 jr1
|

/* end of Block 1 */

/***************************************************************************/
/*                                Block 2                                    */
/***************************************************************************/

calendar:= Calendar new.

agvSystem:= AGVSystem newWithDispatchingRule:'Shortest Remaining Routing'
                        withAgvSelectionRule:'Lowest Utilization'
                        withStagingAreaSelectionRule:'Least Utilization'
                        withTrackIntersecControlRule:'First Come-First Serve'.

    p1:=ControlPoint newWithName: 'p1'.
    p2:=ControlPoint newWithName: 'p2'.
    p3:=ControlPoint newWithName:  'p3'.
    p4:=ControlPoint newWithName: 'p4'.
    p5:=ControlPoint newWithName: 'p5'.
    p6:=ControlPoint newWithName:  'p6'.
    p7:=ControlPoint newWithName: 'p7'.
    p8:=ControlPoint newWithName:  'p8'.
    p9:=ControlPoint newWithName:  'p9'.
    p10:=ControlPoint newWithName:  'p10'.
    p11:=StagingArea newWithName:  'p11'.
    p12:=StagingArea newWithName:  'p12'.
    p13:=ControlPoint newWithName:  'p13'.

 s1:= TrackSegment newWithName: 's1' withStartPoint: p1 withEndPoint: p2
withLength: 15.
 s2:= TrackSegment newWithName: 's2' withStartPoint: p2 withEndPoint: p3
withLength: 15.
 s3:= TrackSegment newWithName: 's3' withStartPoint: p3 withEndPoint: p4
withLength: 10.
 s4:= TrackSegment newWithName: 's4' withStartPoint: p4 withEndPoint: p5
withLength: 15.
 s5:= TrackSegment newWithName: 's5' withStartPoint: p5 withEndPoint: p6
withLength: 15.
 s6:= TrackSegment newWithName: 's6' withStartPoint: p6 withEndPoint: p7
withLength: 10.
 s7:= TrackSegment newWithName: 's7' withStartPoint: p7 withEndPoint: p8
withLength: 14.
 s8:= TrackSegment newWithName: 's8' withStartPoint: p8 withEndPoint: p9
withLength: 10.
 s9:= TrackSegment newWithName: 's9' withStartPoint: p9 withEndPoint: p10
withLength: 10.
```

Figure 7.3 IASE Simulation Model

```
 s10:= TrackSegment newWithName: 's10' withStartPoint: p10 withEndPoint: p13
withLength: 10.
 s11:= TrackSegment newWithName: 's11' withStartPoint: p9 withEndPoint: p11
withLength: 10.
 s12:= TrackSegment newWithName: 's12' withStartPoint: p11 withEndPoint: p10
withLength: 10.
 s13:= TrackSegment newWithName: 's13' withStartPoint: p13 withEndPoint: p1
withLength: 10.
 s14:= TrackSegment newWithName: 's14' withStartPoint: p10 withEndPoint: p12
withLength: 10.
 s15:= TrackSegment newWithName: 's15' withStartPoint: p12 withEndPoint: p13
withLength: 10.

agv1:= AGV newWith: 'AGV1'
       andCurrentLocation: p3
       andLoadingTime: 3
       andUnloadingTime: 3
       andSpeedWhenEmpty: 4.5
       andSpeedWhenLoaded: 4.0
       andAcceleration: 4
       andDeceleration: 4.5
       andBatteryCapacity: 13000
       andTravelEmptyBatteryConsumption: 3
       andTravelLoadedBatteryConsumption: 3
       andAccelerationBatteryConsumption: 5
       andDecelerationBatteryConsumption: 6
       andLoadingBatteryConsumption: 5
       andUnloadingBatteryConsumption: 5
       andChargingUnitDuration: 2
       andIdleLocation: (Array with: p11)
       andTimeBetweenBreakDowns: (Exponential newLambda:0.00000007)
       andMaintenanceTime: (Exponential newLambda:0.022 ).

agv2:= AGV newWith: 'AGV2'
       andCurrentLocation: p1
       andLoadingTime: 3
       andUnloadingTime: 3
       andSpeedWhenEmpty: 4.5
       andSpeedWhenLoaded: 4.0
       andAcceleration: 4
       andDeceleration: 4.5
       andBatteryCapacity: 13000
       andTravelEmptyBatteryConsumption: 3
       andTravelLoadedBatteryConsumption: 3
       andAccelerationBatteryConsumption: 5
       andDecelerationBatteryConsumption: 6
       andLoadingBatteryConsumption: 5
       andUnloadingBatteryConsumption: 5
       andChargingUnitDuration: 2
       andIdleLocation: (Array with: p12)
       andTimeBetweenBreakDowns: (Exponential newLambda:0.0000007)
       andMaintenanceTime: (Exponential newLambda:0.022 ).

/* end of block 2 */
```

Figure 7.3 (Continued)

```
/*****************************************************************************/
/*                                Block 3                                    */
/*****************************************************************************/

blackBoardStr := BlackBoardStructure initializeBlackBoard.

/* end of Block 3 */

/*****************************************************************************/
/*                                Block 4                                    */
/*****************************************************************************/

machineA:= InputStation newWithName: 'machA'
       andServerNumber: 10
       andInputQueues: 1
       andInputQueueSize: #(100)
       andInputLocation: p1
       andOutputQueueSize: 100
       andOutputLocation: p2.

/* end of block 4 */

/*****************************************************************************/
/*                                Block 5                                    */
/*****************************************************************************/

machine1:= MISOQueueMServerProc newWithName: 'mach1'
       andServerNumber: 2
       andInputQueues: 1
       andInputQueueSize: #(100)
       andInputLocation: p3
       andOutputQueueSize: 100
       andOutputLocation: p4
       partBreakDownDisposition: 'process remaining time'
       andTimeBetweenBreakDowns: (NormalDist newMu: 10000000 sigma: 0)
       andMaintenanceTime: (Exponential newLambda:0.01).

machine1 addBatchFormat: #('part A' 1 'part A' 1 'part A' 1).
machine1 addBatchFormat: #('part B' 1 'part B' 1 'part B' 1).
machine1 addBatchFormat: #('part A' 1 'part A' 1 'part C' 1).
machine1 addBatchFormat: #('part B' 1 'part B' 1 'part C' 1).

machine2:= MISOQueueMServerProc newWithName: 'mach2'
       andServerNumber: 2
       andInputQueues: 1
       andInputQueueSize: #(200)
       andInputLocation: p5
       andOutputQueueSize: 200
       andOutputLocation: p6
       partBreakDownDisposition: 'process remaining time'
       andTimeBetweenBreakDowns: (NormalDist newMu: 10080 sigma: 0)
       andMaintenanceTime: (NormalDist newMu: 840 sigma: 0).

machine2 addBatchFormat: #('allParts' 3).
```

Figure 7.3 (Continued)

```
machine3:= MISOQueueMServerProc newWithName: 'mach3'
       andServerNumber: 1 andInputQueues: 1
       andInputQueueSize: #(200)
       andInputLocation: p7
       andOutputQueueSize: 200
       andOutputLocation: p8
       partBreakDownDisposition: 'process remaining time'
       andTimeBetweenBreakDowns: (NormalDist newMu: 10000000 sigma: 0)
       andMaintenanceTime: (Exponential newLambda:0.01).

machine3 addBatchFormat: #('part A' 3).
machine3 addBatchFormat: #('part B' 3).
machine3 addBatchFormat: #('part C' 3).

term:= Terminator newWithName:' Final Terminator'.

/* end of Block 5 */


/*******************************************************************************/
/*                                  Block 6                                    */
/*******************************************************************************/

machCell1:=(MachineCell newWithName: 'cell1')
                        addMachine: machine1.
machCell2:=(MachineCell newWithName: 'cell2')
                        addMachine: machine2.
machCell3:=(MachineCell newWithName: 'cell3')
                        addMachine: machine3.

/* end of Block 6 */

/*******************************************************************************/
/*                                  Block 7                                    */
/*******************************************************************************/

cp1 := CellPath newWithName: 'cp1' betweenCells: 'cell1' and: 'cell2' withTime:
1.
cp2 := CellPath newWithName: 'cp2' betweenCells: 'cell2' and: 'cell3' withTime:
1.

/* end of Block 7 */

/*******************************************************************************/
/*                                  Block 8                                    */
/*******************************************************************************/

(ShopFloorMap withNewName: 'map1')
        addCellPath: cp1;
        addCellPath: cp2.

/* end of Block 8 */
```

Figure 7.3 (Continued)

```
/****************************************************************************/
/*                              Block 9                                    */
/****************************************************************************/

op1 := ProductionOperator newWithName: 'op1'
       dedicatedToMachCell: #('cell1' 'cell2')
       currentPosition: 'cell1'
       shiftLength: 540
       breakLength: 60
       breakTimes: 2
       meetingLength: 60
       meetingTimes: 1
       machinePolicy: 'LQF'
       jobPriorityRule: 'OPF'.

op2 := ProductionOperator newWithName: 'op2'
       dedicatedToMachCell: #('cell2' 'cell3')
       currentPosition: 'cell2'
       shiftLength: 540
       breakLength: 60
       breakTimes: 2
       meetingLength: 60
       meetingTimes: 1
       machinePolicy: 'LQF'
       jobPriorityRule: 'OPF'.

/* end of Block 9 */

/****************************************************************************/
/*                              Block 10                                   */
/****************************************************************************/

mt1 := MaintenanceTechnician newWithName: 'mt1'
       dedicatedToMachines: #('mach1' 'mach2' 'mach3')
       currentPosition: 'cell3'
       shiftLength: 600
       breakLength: 45
       breakTimes: 2
       meetingLength: 30
       meetingTimes: 1
       machinePolicy: 'FIFO'.

mt1 addPreventiveMaintenanceScheduleFor: 'mach1'
       intervalBetweenMaintenance: 1440 timeLength: 75.
mt1 addPreventiveMaintenanceScheduleFor: 'mach2'
       intervalBetweenMaintenance: 720 timeLength: 120.
mt1 addPreventiveMaintenanceScheduleFor: 'mach3'
       intervalBetweenMaintenance: 540 timeLength: 30.
mt1 schedulePreventiveMaintenance.

/* end of block 10*/
```

Figure 7.3 (Continued)

```
/****************************************************************************/
/*                               Block 11                                   */
/****************************************************************************/

jr1 := (JobReleaser newWithName: 'jr1' locatesAt: machineA)
      addMonitoredMachine: 'mach1'
            andMonitoringRule: 'utilization' andStandardValue: 1.2;
      addMonitoredMachine: 'mach2'
            andMonitoringRule: 'queue' andStandardValue: 30;
      addMonitoredMachine: 'mach3'
            andMonitoringRule: 'queue' andStandardValue: 40.

/* end of Block 11 */

/****************************************************************************/
/*                               Block 12                                   */
/****************************************************************************/

routing1:= Routing new.
routing1 addOperation: machineA key: 1
                processingTime: [:rg | rg normalMu: 0 sigma: 0]
                setupTime: nil
                unloadingTime: nil;
                addOperation: machine1 key: 1
                processingTime: [:rg | rg normalMu: 225 sigma: 0]
                setupTime: [:rg | rg normalMu: 20 sigma: 0]
                unloadingTime: [:rg | rg normalMu: 40 sigma: 0];
                addOperation: machine2 key: 1
                processingTime: [:rg | rg normalMu: 30 sigma: 0]
                setupTime: [:rg | rg normalMu: 15 sigma: 0]
                unloadingTime: [:rg | rg normalMu: 15 sigma: 0];
                addOperation: machine3 key: 1
                processingTime: [:rg | rg  normalMu: 55 sigma: 0]
                setupTime: [:rg | rg normalMu: 10 sigma: 0]
                unloadingTime: [:rg | rg normalMu: 10 sigma: 0];
                addOperation: machine2 key: 1
                processingTime: [:rg | rg normalMu: 50 sigma: 0]
                setupTime: [:rg | rg normalMu: 15 sigma: 0]
                unloadingTime: [:rg | rg normalMu: 15 sigma: 0];
                addOperation: machine1 key: 1
                processingTime: [:rg | rg normalMu: 255 sigma: 0]
                setupTime: [:rg | rg normalMu: 20 sigma: 0]
                unloadingTime: [:rg | rg normalMu: 40 sigma: 0];
                addOperation: machine3 key: 1
                processingTime: [:rg | rg  normalMu: 10 sigma: 0]
                setupTime: [:rg | rg normalMu: 10 sigma: 0]
                unloadingTime: [:rg | rg normalMu: 10 sigma: 0];

                addOperation: term key: nil.
```

Figure 7.3 (Continued)

```
routing2:= Routing new.
routing2 addOperation: machineA key: 1
                processingTime: [:rg | rg normalMu: 0 sigma: 0]
                setupTime: nil
                unloadingTime: nil;
                addOperation: machine1 key: 1
                processingTime: [:rg | rg normalMu: 225 sigma: 0]
                setupTime: [:rg | rg normalMu: 20 sigma: 0]
                unloadingTime: [:rg | rg normalMu: 40 sigma: 0];
                addOperation: machine2 key: 1
                processingTime: [:rg | rg normalMu: 30 sigma: 0]
                setupTime: [:rg | rg normalMu: 15 sigma: 0]
                unloadingTime: [:rg | rg normalMu: 15 sigma: 0];
                addOperation: machine3 key: 1
                processingTime: [:rg | rg  normalMu: 55 sigma: 0]
                setupTime: [:rg | rg normalMu: 10 sigma: 0]
                unloadingTime: [:rg | rg normalMu: 10 sigma: 0];
                addOperation: machine2 key: 1
                processingTime: [:rg | rg normalMu: 50 sigma: 0]
                setupTime: [:rg | rg normalMu: 15 sigma: 0]
                unloadingTime: [:rg | rg normalMu: 15 sigma: 0];
                addOperation: machine1 key: 1
                processingTime: [:rg | rg normalMu: 255 sigma: 0]
                setupTime: [:rg | rg normalMu: 20 sigma: 0]
                unloadingTime: [:rg | rg normalMu: 40 sigma: 0];
                addOperation: machine3 key: 1
                processingTime: [:rg | rg  normalMu: 10 sigma: 0]
                setupTime: [:rg | rg normalMu: 10 sigma: 0]
                unloadingTime: [:rg | rg normalMu: 10 sigma: 0];
                addOperation: term key: nil.

routing3:= Routing new.
routing3 addOperation: machineA key: 1
                processingTime: [:rg | rg normalMu: 0 sigma: 0]
                setupTime: nil
                unloadingTime: nil;
                addOperation: machine1 key: 1
                processingTime: [:rg | rg normalMu: 225 sigma: 0]
                setupTime: [:rg | rg normalMu: 20 sigma: 0]
                unloadingTime: [:rg | rg normalMu: 40 sigma: 0];
                addOperation: machine2 key: 1
                processingTime: [:rg | rg normalMu: 30 sigma: 0]
                setupTime: [:rg | rg normalMu: 15 sigma: 0]
                unloadingTime: [:rg | rg normalMu: 15 sigma: 0];
                addOperation: machine3 key: 1
                processingTime: [:rg | rg  normalMu: 55 sigma: 0]
                setupTime: [:rg | rg normalMu: 10 sigma: 0]
                unloadingTime: [:rg | rg normalMu: 10 sigma: 0];
                addOperation: machine3 key: 1
                processingTime: [:rg | rg  normalMu: 10 sigma: 0]
                setupTime: [:rg | rg normalMu: 10 sigma: 0]
                unloadingTime: [:rg | rg normalMu: 10 sigma: 0];
                addOperation: term key: nil.

/* end of Block 12 */
```

Figure 7.3 (Continued)

```
/****************************************************************************/
/*                              Block 13                                    */
/****************************************************************************/

workOrder1:= WorkOrder newWorkOrderType: 'Work Order 1'.
workOrder2:= WorkOrder newWorkOrderType: 'Work Order 2'.
workOrder3:= WorkOrder newWorkOrderType: 'Work Order 3'.
WorkOrder setWorkOrderNumber: 1.

workOrder1 addComponentWFI: 'part A' andCWFIRouting: routing1 andPriorityValue:
1.
workOrder2 addComponentWFI: 'part B' andCWFIRouting: routing2 andPriorityValue:
2.
workOrder3 addComponentWFI: 'part C' andCWFIRouting: routing3 andPriorityValue:
3.

creater1:= WOCreator newWithWorkOrder: workOrder1
           timeBetweenCreationsGenerator: (NormalDist newMu: 204 sigma: 0).

creater2:= WOCreator newWithWorkOrder: workOrder2
           timeBetweenCreationsGenerator: (NormalDist newMu: 336 sigma: 0).

creater3:= WOCreator newWithWorkOrder: workOrder3
           timeBetweenCreationsGenerator: (NormalDist newMu: 3360 sigma: 0).

calendar schedule: [creater1 create] at: 0.
calendar schedule: [creater2 create] at: 0.
calendar schedule: [creater3 create] at: 0.

calendar schedule: [calendar clearStatistics] at: 131040.
calendar schedule: [calendar end] at: 262080.

calendar addToListOfSystemElements: machine1;
         addToListOfSystemElements: machine2;
         addToListOfSystemElements: machine3;
         addToListOfSystemElements: op1;
         addToListOfSystemElements: op2;
         addToListOfSystemElements: jr1;
         addToListOfSystemElements: mt1.
calendar eventInitiator]

/* end of block 13 */
```

Figure 7.3 (Continued)

Table 13

Input Station Class Keyword Specifications

Keyword	Function
newWithName:	name of the input station
andServerNumber:	number of servers in the input station
andInputQueue:	number of input queue
andInputQueueSize:	size of each input queue
andInputLocation:	location of input queue
andOutputQueueSize:	size of output queue
andOutputQueueLocation:	location of output queue

Table 14

Machine Class Keyword Specifications

Keyword	Function
newWithName:	name of the machine
andServerNumber:	number of servers in the machine
andInputQueue:	number of input queue
andInputQueueSize:	size of each input queue
andInputLocation:	location of input queue
andOutputQueueSize:	size of output queue
andOutputQueueLocation:	location of output queue
partBreakDownDisposition:	part disposition option after break down
andTimeBetweenBreakDown:	interarrival time between break downs
andMaintenanceTime:	length of emergency maintenance
addBatchFormat:	add a new batch format; every two elements in batch format array represents a part type name and number of that part type allowed in the batch format. A part type name has to correspond to the name of work flow item. 'allParts' is a keyword to represent all type of work flow item.

Block 6 defines the instances of machine cell to include certain machines into each cells. The keyword, 'newWithName:' along with the name of the cell is used to generate an instance of machine cell. Then, machines are added to each cell using the 'addMachine:' message. Table 15 briefly describes machine cell class keywords.

Table 15

Machine Cell Class Keyword Specifications

Keyword	Function
newWithName:	name of the machine cell
addMachine:	add an instance of machine into the cell

Block 7 defines the paths between machine cells. Specifications of Cell Path keywords are shown in Table 16.

Table 16

Cell Path Class Keyword Specifications

Keyword	Function
newWithName:	name of the cell path
betweenCells: and:	the cell path represents a cell name to another cell name
withTime:	travel time between two machine cells

Block 8 defines an instance of shop floor map to include all the instances of cell paths. No local variable points to the shop floor map instance. In fact, the keyword, 'newWithName:' internally triggers the initialization of a global shop floor map instance in the system. The keyword, 'addCellPath:' is to add an instance of cell path to the global shop floor map instance. Table 17 lists the functions of shop floor map class keywords.

Table 17

Shop Floor Map Class Keyword Specifications

Keyword	Function
withNewName:	name of the shop floor map
addCellPath:	add an instance of cell path into the instance of shop floor map

Block 9 defines the instances of production operators with machine policy and job priority rules. Each keyword message generates an instance of production operators, which is pointed to a local variable. Table 18 presents the keyword specifications for the production operator class.

Block 10 defines an instance of maintenance technicians with machine policy and preventive maintenance schedules. Like the way of creating instances of production operators,

Table 18

Production Operator Class Keyword Specifications

Keyword	Function
newWithName:	name of the production operator instance
dedicatedToMachcell:	machine cells that the PO is responsible for
currentPosition:	initialized position of the PO
shiftLength:	length of a shift
breakLength:	length of a break
breakTimes:	number of breaks in a shift
meetingLength:	length of a meeting
meetingTimes:	number of meeting in a shift
machinePolicy:	machine policy rule name
jobPriorityRule:	job priority rule name

instances of MT are generated by keyword messages. Specifications of MT class keywords are shown in Table 19.

Block 11 defines an instance of job releaser and sets up standard target values for monitored machines by using a keyword message. The specifications of each keyword are illustrated in Table 20.

Table 19

Maintenance Technician Class Keyword Specifications

Keyword	Function
newWithName:	name of the MT instance
dedicatedToMachcell:	machine cells that the PO is responsible for
currentPosition:	initialized position of the MT in the system
shiftLength:	length per shift
breakLength:	length of a break
breakTimes:	number of breaks per shift
meetingLength:	length of a meeting
meetingTimes:	number of meeting per shift
machine policy:	machine policy rule
addPreventiveMaintenanceScheduleFor:	add a machine (name) for scheduling preventive maintenance
intervalBetweenMaintenance:	interarrival time between PMs
timeLength:	length of per PM
schedulePreventiveMaintenance	initialize PM scheduling

Table 20

Job Releaser Class Keyword Specifications

Keyword	Function
newWithName:	name of the JR instance
locatesAt:	in the location of cell
addMonitoredMachine:	add a machine for monitoring
andMonitoringRule:	name of monitoring rule
andStandardValue:	standard value for the monitoring rule

Block 12 defines the instances of routings and add processing, setup, and unloading time. Although the Routing Class structure is a part of OOMA, the setup and unloading capabilities have been added in IASE. The keywords, 'setupTime:' and 'unloadingTime:' are implemented within routing class structure to define loading time and unloading in a routing operation. Table 21 shows the function specifications of Routing class keywords.

Table 21

Routing Class Keyword Specifications

Keyword	Function
addOperation:	add a routing operation to the routing instance
processingTime:	distribution of processing time length
setupTime:	distribution of setup (loading) time length
unloadingTime:	distribution of unloading time length

Block 13 is the standard model specifications from OOMA. Please refer to OOMA (Beaumariage, 1990).

Chapter 8. Conclusions and Future Research

8.1 Conclusions

IASE is an architecture which addresses a common limitation of current simulation environments, the inability to describe human workers' decision making processes. IASE includes several common manufacturing activities in the form of reusable modules, such as machine break downs, preventive maintenance, and machine policy and job priority base rules. This allows users to reuse these features without recreating them for each model. The common modules can also be modified to become different scenarios along with different input configurations without changing the modules' nature.

IASE is developed in an object oriented fashion. In other words, the sub-structures of IASE represent the elements derived from the distributed artificial intelligence concept. Its benefit is to ease future extensions and modifications, because interfacing tasks while making extensions are reduced by separately dealing with less-complicated sub-structures.

8.2 Future Research

8.2.1 Graphical Simulation User Interface

A graphical interface for implementing a complex simulation models is important. IASE requires modelers to have some object oriented programming (OOP) and manufacturing layout design knowledge in order to model desired systems because IASE does not include a full featured graphical interface. A graphical user interface will eliminate the requirement of understanding textual structures of a simulation environment. As a consequence, a user from the general manufacturing shop floor, with basic simulation concepts could successfully access the simulation environment.

SLAM II is one of the simulation packages that has a graphical user interface where several conceptual simulation modules are represented graphically. The time consumed in creating a model in those kinds of graphical interface environments is reduced. However, those packages do not have the IA simulation ability or/and flexibility.

8.2.2 Knowledge Base Extensions

A knowledge base storing several heuristic algorithms combining different machine policies and job priorities can lift intelligent agent simulation to another level. With a heuristic algorithm knowledge base, IAs can apply certain job priority and machine policy rule based on the heuristic algorithm to increase system efficiency. On the other hand, IAs' operations are characterized by heuristic algorithms. In addition, a learning knowledge base may be another type of heuristic with a self-improving function. The learning knowledge base would store empirical experience from the scenarios that have been executed. Then, the learning knowledge base, based on previous experience, creates another type of heuristic to characterize and improve the IAs' working behavior. The hardware capacity and real time efficiency will be key factors for this research topic.

8.2.3 Policy Specification Language

A policy specification language allows modelers to use logic when defining specific mixed machine policies. In other words, the policy specification language utilizes a series of if-then rules or similar for IAs to execute available machine policies. In IASE, each IA can only carry one machine policy at a time. They are not sophisticated enough to adjust different machine policies corresponding to the system performance. The benefit of having a policy specification language is to allow system modelers to tackle just IA smart decision logic without dealing with other system configurations.

8.2.4 IA Simulation Beyond Shop Floor

Extending IA simulation ability above the shop floor to include Master Production Scheduling (MRP) features is another research area. In addition to manufacturing shop floor IAs, production management IAs for controlling product due date, lead time, and storage space can enlarge the domain of manufacturing simulations. This will combine production management and shop floor manufacturing simulation together as a simulation environment.

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Guided Vehicle (AGV) Systems, Oregon State University, Master Thesis, 1995.

Appendices

Appendix A: SLAM II Simulation Model for Case Study 1

SLAM II Model Network Code

```
RESOURCE,M2,5;
      RESOURCE,M1(2),2;
      RESOURCE,M3,8;
      RESOURCE,AGV(2),11,12,13,14,15,16;
      RESOURCE,MT,10;
      RESOURCE,PO(2),21,22,23,24,25,26;
;
P1    CREATE,RNORM(204,5),,1;
      ACTIVITY;
ZAAB  GOON;
      ACTIVITY;
CP1   AWAIT(11),AGV,,1;
      ACTIVITY,1;
      FREE,AGV,1;
      ACTIVITY;
IQ1   QUEUE(1),,,;
      ACTIVITY(1);
      BATCH,1,3,,,ALL(2);
      ACTIVITY;
      AWAIT(21),PO,,1;
      ACTIVITY,20;
      FREE,PO,1;
      ACTIVITY;
      AWAIT(2),M1,,1;
      ACTIVITY/11,RNORM(225,5),,;M1 AND 1;
      ACTIVITY/12,RNORM(225,5),,;M1 AND 2;
      FREE,M1,1;
      ACTIVITY;
      AWAIT(22),PO,,1;
      ACTIVITY,40;
      FREE,PO,1;
      ACTIVITY;
      UNBATCH,2,1;
      ACTIVITY;
OQ1   QUEUE(3),,,;
      ACTIVITY(1);
CP2   AWAIT(12),AGV,,1;
      ACTIVITY,1;
      FREE,AGV,1;
      ACTIVITY,,,CEL2;
;
P2    CREATE,RNORM(336,5),,1;
      ACTIVITY,,,ZAAB;
;
P3    CREATE,RNORM(3360,5),,1;
      ACTIVITY,,,ZAAB;
;
CEL2  GOON;
      ACTIVITY;
```

```
CP3   AWAIT(13),AGV,,1;
      ACTIVITY,1;
      FREE,AGV,1;
      ACTIVITY;
IQ2   QUEUE(4),,,;
      ACTIVITY(1),,,;LOAD2;
      BATCH,1,3,,,ALL(2);
      ACTIVITY;
      AWAIT(23),PO,,1;
      ACTIVITY,15;
      FREE,PO,1;
      ACTIVITY;
      AWAIT(5),M2,,1;
      ACTIVITY/2,RNORM(85,3);
      FREE,M2,1;
      ACTIVITY;
      AWAIT(24),PO,,1;
      ACTIVITY,15;
      FREE,PO,1;
      ACTIVITY;
      UNBATCH,2,1;
      ACTIVITY;
OQ2   QUEUE(6),,,;
      ACTIVITY(1);
CP4   AWAIT(14),AGV,,1;
      ACTIVITY,1;
      FREE,AGV,1;
      ACTIVITY,,,CEL3;
;
CEL3  GOON;
      ACTIVITY;
CP5   AWAIT(15),AGV,,1;
      ACTIVITY,1;
      FREE,AGV,1;
      ACTIVITY;
IQ3   QUEUE(7),,,;
      ACTIVITY(1),,,;LOAD3;
      BATCH,1,3,,,ALL(2);
      ACTIVITY;
      AWAIT(25),PO,,1;
      ACTIVITY,10;
      FREE,PO,1;
      ACTIVITY;
      AWAIT(8),M3,,1;
      ACTIVITY/3,RNORM(105,3);
      FREE,M3,1;
      ACTIVITY;
      AWAIT(26),PO,,1;
      ACTIVITY,10;
      FREE,PO,1;
      ACTIVITY;
      UNBATCH,2,1;
      ACTIVITY;
OQ3   QUEUE(9),,,;
```

```
       ACTIVITY(1),,,COL;
;
COL    COLCT,INT(1),TIME IN SYS;
       ACTIVITY;
       TERMINATE;
;
       CREATE,RNORM(2000,20);
       ACTIVITY;
       PREEMPT(10),M2,,,1;
       ACTIVITY;
       AWAIT(30),MT;
       ACTIVITY/4,240,,;BREAK DOWN;
       FREE,M2,1;
       ACTIVITY;
       FREE,MT,1;
       ACTIVITY;
       TERMINATE;
       END;
```

SLAM II Model Control Statement Code

```
GEN,CASE 1,THESIS,1/1/2001,10,Y,Y,Y/Y,Y,Y/1,132;
LIMITS,30,2,100;
NETWORK;
INITIALIZE,,100400,Y;
FIN;
```

SLAM II Model User Insert Code

```
SUBROUTINE INTLC
       COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
      1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)

       ETIME = 50000
       CALL SCHDL(1,ETIME,ATRIB)
       END

       SUBROUTINE EVENT(I)
       GO TO(1),I
    1  CALL CLEAR
       RETURN
       END
```

Appendix B: SLAM II Simulation Result for Case Study 1

S L A M   I I   S U M M A R Y   R E P O R T

SIMULATION PROJECT THESIS   BY CASE 1

DATE 1/ 1/2001   RUN NUMBER 1 OF 10

CURRENT TIME .1004E+06
STATISTICAL ARRAYS CLEARED AT TIME .5000E+05

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NO.OF OBS
TIME IN SYS	.683E+03	.130E+03	.191E+00	.513E+03	.105E+04	411

REGULAR ACTIVITY STATISTICS

ACTIVITY INDEX/LABEL	AVERAGE UTILIZATION	STANDARD DEVIATION	MAXIMUM UTIL	CURRENT UTIL	ENTITY COUNT
2 M2	.2341	.4234	1	0	138
3 M3	.2881	.4529	1	1	137
4 BREAK DOWN	.1220	.3273	1	0	26
1 M1	.6150	.4903	2	1	137

RESOURCE STATISTICS

RESOURCE NUMBER	RESOURCE LABEL	CURRENT CAPACITY	AVERAGE UTIL	STANDARD DEVIATION	MAXIMUM UTIL	CURRENT UTIL
1	M2	1	.36	.479	1	0
2	M1	2	.62	.490	2	1
3	M3	1	.29	.453	1	1
4	AGV	2	.04	.268	2	0
5	MT	1	.12	.327	1	0
6	PO	2	.30	.491	2	0

RESOURCE NUMBER	RESOURCE LABEL	CURRENT AVAILABLE	AVERAGE AVAILABLE	MINIMUM AVAILABLE	MAXIMUM AVAILABLE

1	M2	1	.6439	0	1
2	M1	1	1.3850	0	2
3	M3	0	.7119	0	1
4	AGV	2	1.9591	0	2
5	MT	1	.8780	0	1
6	PO	2	1.7001	0	2

S L A M I I S U M M A R Y R E P O R T

SIMULATION PROJECT THESIS BY CASE 1

DATE 1/ 1/2001 RUN NUMBER 2 OF 10

CURRENT TIME .1004E+06
STATISTICAL ARRAYS CLEARED AT TIME .5000E+05

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NO.OF OBS
TIME IN SYS	.682E+03	.131E+03	.193E+00	.519E+03	.110E+04	414

REGULAR ACTIVITY STATISTICS

ACTIVITY INDEX/LABEL	AVERAGE UTILIZATION	STANDARD DEVIATION	MAXIMUM UTIL	CURRENT UTIL	ENTITY COUNT
2 M2	.2334	.4230	1	0	138
3 M3	.2877	.4527	1	0	138
4 BREAK DOWN	.1214	.3266	1	0	26
1 M1	.6161	.4895	2	1	137

RESOURCE STATISTICS

RESOURCE NUMBER	RESOURCE LABEL	CURRENT CAPACITY	AVERAGE UTIL	STANDARD DEVIATION	MAXIMUM UTIL	CURRENT UTIL
1	M2	1	.35	.478	1	0
2	M1	2	.62	.489	2	1
3	M3	1	.29	.453	1	0
4	AGV	2	.04	.268	2	0
5	MT	1	.12	.327	1	0
6	PO	2	.30	.496	2	0

RESOURCE NUMBER	RESOURCE LABEL	CURRENT AVAILABLE	AVERAGE AVAILABLE	MINIMUM AVAILABLE	MAXIMUM AVAILABLE
1	M2	1	.6451	0	1
2	M1	1	1.3839	0	2
3	M3	1	.7123	0	1
4	AGV	2	1.9591	0	2
5	MT	1	.8786	0	1
6	PO	2	1.6999	0	2

S L A M I I S U M M A R Y R E P O R T

SIMULATION PROJECT THESIS BY CASE 1

DATE 1/ 1/2001 RUN NUMBER 3 OF 10

CURRENT TIME .1004E+06
STATISTICAL ARRAYS CLEARED AT TIME .5000E+05

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NO.OF OBS
TIME IN SYS	.681E+03	.131E+03	.193E+00	.516E+03	.110E+04	411

REGULAR ACTIVITY STATISTICS

ACTIVITY INDEX/LABEL	AVERAGE UTILIZATION	STANDARD DEVIATION	MAXIMUM UTIL	CURRENT UTIL	ENTITY COUNT
2 M2	.2305	.4211	1	1	137
3 M3	.2849	.4514	1	0	137
4 BREAK DOWN	.1238	.3294	1	0	26
1 M1	.6111	.4890	2	1	137

RESOURCE STATISTICS

RESOURCE NUMBER	RESOURCE LABEL	CURRENT CAPACITY	AVERAGE UTIL	STANDARD DEVIATION	MAXIMUM UTIL	CURRENT UTIL
1	M2	1	.35	.478	1	1

2	M1	2	.61	.489	2	1
3	M3	1	.28	.451	1	0
4	AGV	2	.04	.268	2	0
5	MT	1	.12	.329	1	0
6	PO	2	.30	.495	2	0

RESOURCE NUMBER	RESOURCE LABEL	CURRENT AVAILABLE	AVERAGE AVAILABLE	MINIMUM AVAILABLE	MAXIMUM AVAILABLE
1	M2	0	.6457	0	1
2	M1	1	1.3889	0	2
3	M3	1	.7151	0	1
4	AGV	2	1.9592	0	2
5	MT	1	.8762	0	1
6	PO	2	1.7006	0	2

S L A M I I S U M M A R Y R E P O R T

SIMULATION PROJECT THESIS BY CASE 1

DATE 1/ 1/2001 RUN NUMBER 4 OF 10

CURRENT TIME .1004E+06
STATISTICAL ARRAYS CLEARED AT TIME .5000E+05

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NO.OF OBS
TIME IN SYS	.677E+03	.127E+03	.188E+00	.515E+03	.106E+04	411

REGULAR ACTIVITY STATISTICS

ACTIVITY INDEX/LABEL	AVERAGE UTILIZATION	STANDARD DEVIATION	MAXIMUM UTIL	CURRENT UTIL	ENTITY COUNT
2 M2	.2324	.4224	1	0	138
3 M3	.2854	.4516	1	1	137
4 BREAK DOWN	.1212	.3263	1	0	26
1 M1	.6162	.4885	2	1	137

RESOURCE STATISTICS

RESOURCE NUMBER	RESOURCE LABEL	CURRENT CAPACITY	AVERAGE UTIL	STANDARD DEVIATION	MAXIMUM UTIL	CURRENT UTIL
1	M2	1	.35	.478	1	0
2	M1	2	.62	.489	2	1
3	M3	1	.29	.452	1	1
4	AGV	2	.04	.268	2	0
5	MT	1	.12	.326	1	0
6	PO	2	.30	.502	2	0

RESOURCE NUMBER	RESOURCE LABEL	CURRENT AVAILABLE	AVERAGE AVAILABLE	MINIMUM AVAILABLE	MAXIMUM AVAILABLE
1	M2	1	.6464	0	1
2	M1	1	1.3838	0	2
3	M3	0	.7146	0	1
4	AGV	2	1.9591	0	2
5	MT	1	.8788	0	1
6	PO	2	1.7003	0	2

S L A M   I I   S U M M A R Y   R E P O R T

SIMULATION PROJECT THESIS BY CASE 1

DATE 1/ 1/2001 RUN NUMBER 5 OF 10

CURRENT TIME .1004E+06
STATISTICAL ARRAYS CLEARED AT TIME .5000E+05

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NO.OF OBS
TIME IN SYS	.685E+03	.132E+03	.193E+00	.512E+03	.112E+04	411

REGULAR ACTIVITY STATISTICS

ACTIVITY INDEX/LABEL	AVERAGE UTILIZATION	STANDARD DEVIATION	MAXIMUM UTIL	CURRENT UTIL	ENTITY COUNT
2 M2	.2333	.4229	1	0	138
3 M3	.2849	.4514	1	1	137
4 BREAK DOWN	.1238	.3294	1	0	26

1 M1	.6101	.4896	2	1	138

RESOURCE STATISTICS

RESOURCE NUMBER	RESOURCE LABEL	CURRENT CAPACITY	AVERAGE UTIL	STANDARD DEVIATION	MAXIMUM UTIL	CURRENT UTIL
1	M2	1	.36	.479	1	0
2	M1	2	.61	.490	2	1
3	M3	1	.28	.451	1	1
4	AGV	2	.04	.269	2	0
5	MT	1	.12	.329	1	0
6	PO	2	.30	.493	2	0

RESOURCE NUMBER	RESOURCE LABEL	CURRENT AVAILABLE	AVERAGE AVAILABLE	MINIMUM AVAILABLE	MAXIMUM AVAILABLE
1	M2	1	.6429	0	1
2	M1	1	1.3899	0	2
3	M3	0	.7151	0	1
4	AGV	2	1.9590	0	2
5	MT	1	.8762	0	1
6	PO	2	1.6990	0	2

S L A M I I S U M M A R Y R E P O R T

SIMULATION PROJECT THESIS BY CASE 1

DATE 1/ 1/2001 RUN NUMBER 6 OF 10

CURRENT TIME .1004E+06
STATISTICAL ARRAYS CLEARED AT TIME .5000E+05

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NO.OF OBS
TIME IN SYS	.682E+03	.130E+03	.191E+00	.517E+03	.108E+04	411

REGULAR ACTIVITY STATISTICS

ACTIVITY	AVERAGE	STANDARD	MAXIMUM	CURRENT	ENTITY

INDEX/LABEL	UTILIZATION	DEVIATION	UTIL	UTIL	COUNT
2 M2	.2335	.4231	1	0	138
3 M3	.2852	.4515	1	1	137
4 BREAK DOWN	.1238	.3294	1	0	26
1 M1	.6131	.4897	2	0	138

RESOURCE STATISTICS

RESOURCE NUMBER	RESOURCE LABEL	CURRENT CAPACITY	AVERAGE UTIL	STANDARD DEVIATION	MAXIMUM UTIL	CURRENT UTIL
1	M2	1	.36	.479	1	0
2	M1	2	.61	.490	2	0
3	M3	1	.29	.452	1	1
4	AGV	2	.04	.269	2	0
5	MT	1	.12	.329	1	0
6	PO	2	.30	.497	2	0

RESOURCE NUMBER	RESOURCE LABEL	CURRENT AVAILABLE	AVERAGE AVAILABLE	MINIMUM AVAILABLE	MAXIMUM AVAILABLE
1	M2	1	.6427	0	1
2	M1	2	1.3869	0	2
3	M3	0	.7148	0	1
4	AGV	2	1.9590	0	2
5	MT	1	.8762	0	1
6	PO	2	1.6994	0	2

S L A M I I S U M M A R Y R E P O R T

SIMULATION PROJECT THESIS BY CASE 1

DATE 1/ 1/2001 RUN NUMBER 7 OF 10

CURRENT TIME .1004E+06
STATISTICAL ARRAYS CLEARED AT TIME .5000E+05

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NO.OF OBS
TIME IN SYS	.678E+03	.130E+03	.192E+00	.516E+03	.111E+04	411

REGULAR ACTIVITY STATISTICS

ACTIVITY INDEX/LABEL	AVERAGE UTILIZATION	STANDARD DEVIATION	MAXIMUM UTIL	CURRENT UTIL	ENTITY COUNT
2 M2	.2308	.4213	1	0	138
3 M3	.2877	.4527	1	1	137
4 BREAK DOWN	.1224	.3277	1	0	26
1 M1	.6148	.4908	2	1	138

RESOURCE STATISTICS

RESOURCE NUMBER	RESOURCE LABEL	CURRENT CAPACITY	AVERAGE UTIL	STANDARD DEVIATION	MAXIMUM UTIL	CURRENT UTIL
1	M2	1	.35	.478	1	0
2	M1	2	.61	.491	2	1
3	M3	1	.29	.453	1	1
4	AGV	2	.04	.269	2	0
5	MT	1	.12	.328	1	0
6	PO	2	.30	.496	2	0

RESOURCE NUMBER	RESOURCE LABEL	CURRENT AVAILABLE	AVERAGE AVAILABLE	MINIMUM AVAILABLE	MAXIMUM AVAILABLE
1	M2	1	.6468	0	1
2	M1	1	1.3852	0	2
3	M3	0	.7123	0	1
4	AGV	2	1.9590	0	2
5	MT	1	.8776	0	1
6	PO	2	1.6990	0	2

S L A M   I I   S U M M A R Y   R E P O R T

SIMULATION PROJECT THESIS　　BY CASE 1

DATE 1/ 1/2001　　RUN NUMBER 8 OF 10

CURRENT TIME .1004E+06
STATISTICAL ARRAYS CLEARED AT TIME .5000E+05

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NO.OF OBS
TIME IN SYS	.678E+03	.131E+03	.193E+00	.517E+03	.112E+04	411

REGULAR ACTIVITY STATISTICS

ACTIVITY INDEX/LABEL	AVERAGE UTILIZATION	STANDARD DEVIATION	MAXIMUM UTIL	CURRENT UTIL	ENTITY COUNT
2 M2	.2312	.4216	1	1	137
3 M3	.2847	.4513	1	0	137
4 BREAK DOWN	.1207	.3258	1	0	26
1 M1	.6122	.4901	2	0	137

RESOURCE STATISTICS

RESOURCE NUMBER	RESOURCE LABEL	CURRENT CAPACITY	AVERAGE UTIL	STANDARD DEVIATION	MAXIMUM UTIL	CURRENT UTIL
1	M2	1	.35	.478	1	1
2	M1	2	.61	.490	2	0
3	M3	1	.28	.451	1	0
4	AGV	2	.04	.268	2	0
5	MT	1	.12	.326	1	0
6	PO	2	.30	.491	2	0

RESOURCE NUMBER	RESOURCE LABEL	CURRENT AVAILABLE	AVERAGE AVAILABLE	MINIMUM AVAILABLE	MAXIMUM AVAILABLE
1	M2	0	.6481	0	1
2	M1	2	1.3878	0	2
3	M3	1	.7153	0	1
4	AGV	2	1.9592	0	2
5	MT	1	.8793	0	1
6	PO	2	1.7009	0	2

S L A M I I S U M M A R Y R E P O R T

SIMULATION PROJECT THESIS BY CASE 1

DATE 1/ 1/2001 RUN NUMBER 9 OF 10

CURRENT TIME .1004E+06
STATISTICAL ARRAYS CLEARED AT TIME .5000E+05

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NO.OF OBS
TIME IN SYS	.684E+03	.132E+03	.194E+00	.513E+03	.110E+04	414

REGULAR ACTIVITY STATISTICS

ACTIVITY INDEX/LABEL	AVERAGE UTILIZATION	STANDARD DEVIATION	MAXIMUM UTIL	CURRENT UTIL	ENTITY COUNT
2 M2	.2330	.4227	1	0	138
3 M3	.2872	.4524	1	0	138
4 BREAK DOWN	.1190	.3238	1	0	25
1 M1	.6150	.4911	2	1	137

RESOURCE STATISTICS

RESOURCE NUMBER	RESOURCE LABEL	CURRENT CAPACITY	AVERAGE UTIL	STANDARD DEVIATION	MAXIMUM UTIL	CURRENT UTIL
1	M2	1	.35	.478	1	0
2	M1	2	.61	.491	2	1
3	M3	1	.29	.452	1	0
4	AGV	2	.04	.268	2	0
5	MT	1	.12	.324	1	0
6	PO	2	.30	.491	2	0

RESOURCE NUMBER	RESOURCE LABEL	CURRENT AVAILABLE	AVERAGE AVAILABLE	MINIMUM AVAILABLE	MAXIMUM AVAILABLE
1	M2	1	.6479	0	1
2	M1	1	1.3850	0	2
3	M3	1	.7128	0	1
4	AGV	2	1.9591	0	2
5	MT	1	.8810	0	1
6	PO	2	1.6999	0	2

S L A M I I S U M M A R Y R E P O R T

SIMULATION PROJECT THESIS BY CASE 1

DATE 1/ 1/2001 RUN NUMBER 10 OF 10

CURRENT TIME .1004E+06
STATISTICAL ARRAYS CLEARED AT TIME .5000E+05

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN VALUE	STANDARD DEVIATION	COEFF. OF VARIATION	MINIMUM VALUE	MAXIMUM VALUE	NO.OF OBS
TIME IN SYS	.675E+03	.128E+03	.190E+00	.516E+03	.108E+04	411

REGULAR ACTIVITY STATISTICS

ACTIVITY INDEX/LABEL	AVERAGE UTILIZATION	STANDARD DEVIATION	MAXIMUM UTIL	CURRENT UTIL	ENTITY COUNT
2 M2	.2342	.4235	1	1	137
3 M3	.2870	.4524	1	0	137
4 BREAK DOWN	.1220	.3273	1	0	26
1 M1	.6119	.4912	2	0	137

RESOURCE STATISTICS

RESOURCE NUMBER	RESOURCE LABEL	CURRENT CAPACITY	AVERAGE UTIL	STANDARD DEVIATION	MAXIMUM UTIL	CURRENT UTIL
1	M2	1	.36	.479	1	1
2	M1	2	.61	.491	2	0
3	M3	1	.29	.452	1	0
4	AGV	2	.04	.268	2	0
5	MT	1	.12	.327	1	0
6	PO	2	.30	.493	2	0

RESOURCE NUMBER	RESOURCE LABEL	CURRENT AVAILABLE	AVERAGE AVAILABLE	MINIMUM AVAILABLE	MAXIMUM AVAILABLE
1	M2	0	.6438	0	1
2	M1	2	1.3881	0	2
3	M3	1	.7130	0	1
4	AGV	2	1.9591	0	2
5	MT	1	.8780	0	1
6	PO	2	1.7007	0	2

Appendix C: IASE Simulation Model for Case Study 1

```
|p0 p1 p2 p3 p4 p5 p6 p7 p8 p9 s1 s2 s3 s4 s5 s6 s7 s8 s9 agv1 agv2
machineA machine1 machine2 machine3
term agvSystem routing1 routing2 routing3 workOrder1 workOrder2 workOrder3
creater1 creater2 creater3 calendar
machCell1 machCell2 machCell3 blackBoardStr cp1 cp2 cp3 op1 op2 mt1 jr1
|

calendar:= Calendar new.
agvSystem:=
AGVSystem newWithDispatchingRule:'Nearest'
      withAgvSelectionRule:'Lowest Utilization'
      withStagingAreaSelectionRule:'Least Utilization'
      withTrackIntersecControlRule:'First Come-First Serve'.

    p1:=ControlPoint newWithName: 'p1'.
    p2:=ControlPoint newWithName: 'p2'.
    p3:=ControlPoint newWithName:  'p3'.
    p4:=ControlPoint newWithName: 'p4'.
    p5:=ControlPoint newWithName: 'p5'.
    p6:=ControlPoint newWithName:  'p6'.
    p7:=ControlPoint newWithName: 'p7'.
    p8:=ControlPoint newWithName:  'p8'.
    p9:=StagingArea newWithName:  'p9'.

 s1:= TrackSegment newWithName: 's1' withStartPoint: p1 withEndPoint: p2
withLength: 28.
 s2:= TrackSegment newWithName: 's2' withStartPoint: p2 withEndPoint: p3
withLength: 25.
 s3:= TrackSegment newWithName: 's3' withStartPoint: p3 withEndPoint: p4
withLength: 10.
 s4:= TrackSegment newWithName: 's4' withStartPoint: p4 withEndPoint: p5
withLength: 28.
 s5:= TrackSegment newWithName: 's5' withStartPoint: p5 withEndPoint: p6
withLength: 25.
 s6:= TrackSegment newWithName: 's6' withStartPoint: p6 withEndPoint: p7
withLength: 10.
 s7:= TrackSegment newWithName: 's7' withStartPoint: p7 withEndPoint: p8
withLength: 25.
 s8:= TrackSegment newWithName: 's8' withStartPoint: p8 withEndPoint: p9
withLength: 10.
 s9:= TrackSegment newWithName: 's9' withStartPoint: p9 withEndPoint: p1
withLength: 10.

agv1:= AGV newWith: 'AGV1'
       andCurrentLocation: p3
       andLoadingTime: 3
       andUnloadingTime: 3
       andSpeedWhenEmpty: 4.5
       andSpeedWhenLoaded: 4.0
       andAcceleration: 4
       andDeceleration: 4.5
       andBatteryCapacity: 13000
       andTravelEmptyBatteryConsumption: 3
       andTravelLoadedBatteryConsumption: 3
       andAccelerationBatteryConsumption: 5
       andDecelerationBatteryConsumption: 6
       andLoadingBatteryConsumption: 5
```

```
        andUnloadingBatteryConsumption: 5
        andChargingUnitDuration: 2
        andIdleLocation: (Array with: p9)
        andTimeBetweenBreakDowns: (Exponential newLambda:0.00000007)
        andMaintenanceTime: (Exponential newLambda:0.022 ).

agv2:= AGV newWith: 'AGV2'
        andCurrentLocation: p1
        andLoadingTime: 3
        andUnloadingTime: 3
        andSpeedWhenEmpty: 4.5
        andSpeedWhenLoaded: 4.0
        andAcceleration: 4
        andDeceleration: 4.5
        andBatteryCapacity: 13000
        andTravelEmptyBatteryConsumption: 3
        andTravelLoadedBatteryConsumption: 3
        andAccelerationBatteryConsumption: 5
        andDecelerationBatteryConsumption: 6
        andLoadingBatteryConsumption: 5
        andUnloadingBatteryConsumption: 5
        andChargingUnitDuration: 2
        andIdleLocation: (Array with: p9)
        andTimeBetweenBreakDowns: (Exponential newLambda:0.0000007)
        andMaintenanceTime: (Exponential newLambda:0.022 ).

blackBoardStr := BlackBoardStructure initializeBlackBoard.

machineA:= InputStation newWithName: 'machA'
        andServerNumber: 10
        andInputQueues: 1
        andInputQueueSize: #(100)
        andInputLocation: p1
        andOutputQueueSize: 100
        andOutputLocation: p2.

machine1:= MISOQueueMServerProc newWithName: 'mach1'
        andServerNumber: 2
        andInputQueues: 1
        andInputQueueSize: #(100)
        andInputLocation: p3
        andOutputQueueSize: 100
        andOutputLocation: p4
        partBreakDownDisposition: 'process remaining time'
        andTimeBetweenBreakDowns: (Exponential newLambda:0.00000005)
        andMaintenanceTime: (NormalDist newMu: 240 sigma: 0).

machine1 addBatchFormat: #('allParts' 3).

machine2:= MISOQueueMServerProc newWithName: 'mach2'
        andServerNumber: 1
        andInputQueues: 1
        andInputQueueSize: #(2000)
        andInputLocation: p5
        andOutputQueueSize: 200
        andOutputLocation: p6
        partBreakDownDisposition: 'process remaining time'
        andTimeBetweenBreakDowns: (NormalDist newMu: 2000 sigma: 20)
        andMaintenanceTime: (NormalDist newMu: 240 sigma: 0).
```

```
machine2 addBatchFormat: #('allParts' 3).

machine3:= MISOQueueMServerProc newWithName: 'mach3'
       andServerNumber: 1
       andInputQueues: 1
       andInputQueueSize: #(2000)
       andInputLocation: p7
       andOutputQueueSize: 2000
       andOutputLocation: p8
       partBreakDownDisposition: 'process remaining time'
       andTimeBetweenBreakDowns: (Exponential newLambda:0.00000005)
       andMaintenanceTime: (NormalDist newMu: 240 sigma: 0).

machine3 addBatchFormat: #('allParts' 3).

term:= Terminator newWithName:' Final Terminator'.

machCell1:=(MachineCell newWithName: 'cell1')
                            addMachine: machine1.
machCell2:=(MachineCell newWithName: 'cell2')
                         addMachine: machine2.
machCell3:=(MachineCell newWithName: 'cell3')
                         addMachine: machine3.

cp1 := CellPath newWithName: 'cp1' betweenCells: 'cell1' and: 'cell2' withTime:
0.
cp2 := CellPath newWithName: 'cp2' betweenCells: 'cell2' and: 'cell3' withTime:
0.

(ShopFloorMap withNewName: 'map1')
        addCellPath: cp1;
        addCellPath: cp2.

op1 := ProductionOperator newWithName: 'op1'
       dedicatedToMachCell: #('cell1' 'cell2')
       currentPosition: 'cell1'
       shiftLength: 540
       breakLength: 60
       breakTimes: 0
       meetingLength: 60
       meetingTimes: 0
       machinePolicy: 'FIFO'
       jobPriorityRule: 'FIFO'.

op2 := ProductionOperator newWithName: 'op2'
       dedicatedToMachCell: #('cell2' 'cell3')
       currentPosition: 'cell2'
       shiftLength: 540
       breakLength: 60
       breakTimes: 0
       meetingLength: 60
       meetingTimes: 0
       machinePolicy: 'FIFO'
       jobPriorityRule: 'FIFO'.

mt1 := MaintenanceTechnician newWithName: 'mt1'
       dedicatedToMachines: #('mach1' 'mach2' 'mach3')
       currentPosition: 'cell3'
       shiftLength: 600
       breakLength: 45
```

```
        breakTimes: 0
        meetingLength: 30
        meetingTimes: 0
        machinePolicy: 'FIFO'.

routing1:= Routing new.
routing1 addOperation: machineA key: 1
          processingTime: [:rg | rg normalMu: 0 sigma: 0]
          setupTime: nil
          unloadingTime: nil;
          addOperation: machine1 key: 1
          processingTime: [:rg | rg normalMu: 225 sigma: 5]
          setupTime: [:rg | rg normalMu: 20 sigma: 0]
          unloadingTime: [:rg | rg normalMu: 40 sigma: 0];
          addOperation: machine2 key: 1
          processingTime: [:rg | rg normalMu: 85 sigma: 3]
          setupTime: [:rg | rg normalMu: 15 sigma: 0]
          unloadingTime: [:rg | rg normalMu: 15 sigma: 0];
          addOperation: machine3 key: 1
          processingTime: [:rg | rg  normalMu: 105 sigma: 3]
          setupTime: [:rg | rg normalMu: 10 sigma: 0]
          unloadingTime: [:rg | rg normalMu: 10 sigma: 0];
          addOperation: term key: nil.
routing2:= Routing new.
routing2 addOperation: machineA key: 1
          processingTime: [:rg | rg normalMu: 0 sigma: 0]
          setupTime: nil
          unloadingTime: nil;
          addOperation: machine1 key: 1
          processingTime: [:rg | rg normalMu: 225 sigma: 5]
          setupTime: [:rg | rg normalMu: 20 sigma: 0]
          unloadingTime: [:rg | rg normalMu: 40 sigma: 0];
          addOperation: machine2 key: 1
          processingTime: [:rg | rg normalMu: 85 sigma: 3]
          setupTime: [:rg | rg normalMu: 15 sigma: 0]
          unloadingTime: [:rg | rg normalMu: 15 sigma: 0];
          addOperation: machine3 key: 1
          processingTime: [:rg | rg  normalMu: 105 sigma: 3]
          setupTime: [:rg | rg normalMu: 10 sigma: 0]
          unloadingTime: [:rg | rg normalMu: 10 sigma: 0];
          addOperation: term key: nil.
routing3:= Routing new.
routing3 addOperation: machineA key: 1
         processingTime: [:rg | rg normalMu: 0 sigma: 0]
         setupTime: nil
         unloadingTime: nil;
         addOperation: machine1 key: 1
         processingTime: [:rg | rg normalMu: 225 sigma: 5]
         setupTime: [:rg | rg normalMu: 20 sigma: 0]
         unloadingTime: [:rg | rg normalMu: 40 sigma: 0];
         addOperation: machine2 key: 1
         processingTime: [:rg | rg normalMu: 85 sigma: 3]
         setupTime: [:rg | rg normalMu: 15 sigma: 0]
         unloadingTime: [:rg | rg normalMu: 15 sigma: 0];
         addOperation: machine3 key: 1
         processingTime: [:rg | rg  normalMu: 105 sigma: 3]
         setupTime: [:rg | rg normalMu: 10 sigma: 0]
         unloadingTime: [:rg | rg normalMu: 10 sigma: 0];
         addOperation: term key: nil.
```

```
workOrder1:= WorkOrder newWorkOrderType: 'Work Order 1'.
workOrder2:= WorkOrder newWorkOrderType: 'Work Order 2'.
workOrder3:= WorkOrder newWorkOrderType: 'Work Order 3'.
WorkOrder setWorkOrderNumber: 1.

workOrder1 addComponentWFI: 'part 1' andCWFIRouting: routing1 andPriorityValue:
1.
workOrder2 addComponentWFI: 'part 2' andCWFIRouting: routing2 andPriorityValue:
2.
workOrder3 addComponentWFI: 'part 3' andCWFIRouting: routing3 andPriorityValue:
3.

creater1:= WOCreator newWithWorkOrder: workOrder1
           timeBetweenCreationsGenerator:
                    (NormalDist newMu: 204 sigma: 5).

creater2:= WOCreator newWithWorkOrder: workOrder2
           timeBetweenCreationsGenerator:
                    (NormalDist newMu: 336 sigma: 5).

creater3:= WOCreator newWithWorkOrder: workOrder3
           timeBetweenCreationsGenerator:
                    (NormalDist newMu: 3360 sigma: 5).

calendar schedule: [creater1 create] at: 0.
calendar schedule: [creater2 create] at: 0.
calendar schedule: [creater3 create] at: 0.

calendar schedule: [calendar clearStatistics] at: 10000.
calendar schedule: [calendar end] at: 60400.

calendar addToListOfSystemElements: machineA;
         addToListOfSystemElements: machine1;
         addToListOfSystemElements: machine2;
         addToListOfSystemElements: machine3;
         addToListOfSystemElements: agv1;
         addToListOfSystemElements: agv2;
         addToListOfSystemElements: op1;
         addToListOfSystemElements: op2;
         addToListOfSystemElements: mt1.

calendar eventInitiator]
```

Appendix D: IASE Simulation Result for Case Study 1

Simulation Output: Run 1 of 10

```
Calendar Statistics
-------------------
     Event List Length Information
          Time of initialization = 50000.00
          Current Time           = 100400
      Avg Value    Std Dev   Curr Value   Min Value   Max Value  No. Changes
     ----------  ----------  ----------  ----------  ----------  -----------
        11.5346      0.7850     10.0000      8.0000     16.0000        59896

                                  <<< O >>>

 Final Terminator  (a Terminator Object)
----------------------------------------
     Time In System Statistics
          Time of initialization = 50000.00
          Current Time           = 100400
     Total Obs.   Avg Obs.  Std Dev.   Last Obs.   Min Obs.   Max Obs.
     ----------   --------  --------   ---------   --------   --------
            411   912.7503  144.8005   1027.9177   667.5928  1331.6787

                                  <<< O >>>

     mach1  (a Single Queue, Multiple Server Processing Object)
     ----------------------------------------------------------
     Processing Times Information
          Time of initialization = 50000.00
          Current Time           = 100400
     Total Obs.   Avg Obs.  Std Dev.   Last Obs.   Min Obs.   Max Obs.
     ----------   --------  --------   ---------   --------   --------
            138   224.6078    4.6853    233.3061   212.8760   238.0882

     Utilization Information
          Time of initialization = 50000.00
          Current Time           = 100400
      Avg Value    Std Dev   Curr Value   Min Value   Max Value  No. Changes
     ----------  ----------  ----------  ----------  ----------  -----------
         0.6113      0.4897      0.0000      0.0000      2.0000          276

     *InputQueue Information*
     Queue Number 1 Statistics
     Queue Length Statistics
          Time of initialization = 50000.00
          Current Time           = 100400
      Avg Value    Std Dev   Curr Value   Min Value   Max Value  No. Changes
     ----------  ----------  ----------  ----------  ----------  -----------
         1.1419      0.9069      2.0000      0.0000      3.0000          824

     Time In Queue Statistics
          Time of initialization = 50000.00
          Current Time           = 100400
     Total Obs.   Avg Obs.  Std Dev.   Last Obs.   Min Obs.   Max Obs.
     ----------   --------  --------   ---------   --------   --------
            411   139.4795  112.2111     20.0000    20.0000   455.9121
```

```
*OutputQueue Information*
Queue Length Statistics
     Time of initialization = 50000.00
     Current Time           = 100400
 Avg Value    Std Dev    Curr Value   Min Value    Max Value   No. Changes
----------  ----------  ----------  ----------  ----------  -----------
    0.4346      0.8822      0.0000      0.0000      3.0000          829

Time In Queue Statistics
     Time of initialization = 50000.00
     Current Time           = 100400
Total Obs.   Avg Obs.  Std Dev.   Last Obs.   Min Obs.   Max Obs.
----------   --------  --------   ---------   --------   --------
       414    52.9129   32.6121     53.1319     3.2398   190.1064

                        <<< O >>>

mach2  (a Single Queue, Multiple Server Processing Object)
----------------------------------------------------------
Processing Times Information
     Time of initialization = 50000.00
     Current Time           = 100400
Total Obs.   Avg Obs.  Std Dev.   Last Obs.   Min Obs.   Max Obs.
----------   --------  --------   ---------   --------   --------
       139    84.5781    6.6102     86.0232    18.0925    91.1293

Utilization Information
     Time of initialization = 50000.00
     Current Time           = 100400
 Avg Value    Std Dev    Curr Value   Min Value    Max Value   No. Changes
----------  ----------  ----------  ----------  ----------  -----------
    0.2337      0.4232      1.0000      0.0000      1.0000          280

*InputQueue Information*
Queue Number 1 Statistics
Queue Length Statistics
     Time of initialization = 50000.00
     Current Time           = 100400
 Avg Value    Std Dev    Curr Value   Min Value    Max Value   No. Changes
----------  ----------  ----------  ----------  ----------  -----------
    0.5724      1.0261      0.0000      0.0000      3.0000          832

Time In Queue Statistics
     Time of initialization = 50000.00
     Current Time           = 100400
Total Obs.   Avg Obs.  Std Dev.   Last Obs.   Min Obs.   Max Obs.
----------   --------  --------   ---------   --------   --------
       417    70.2959   67.4367     15.0000    15.0000   336.1547

*OutputQueue Information*
Queue Length Statistics
     Time of initialization = 50000.00
     Current Time           = 100400
 Avg Value    Std Dev    Curr Value   Min Value    Max Value   No. Changes
----------  ----------  ----------  ----------  ----------  -----------
    0.4631      0.9246      1.0000      0.0000      6.0000          828

Time In Queue Statistics
     Time of initialization = 50000.00
     Current Time           = 100400
```

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
413	56.3728	40.0436	52.4992	6.2132	217.8708

<<< O >>>

mach3 (a Single Queue, Multiple Server Processing Object)

Processing Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
137	105.0041	2.9436	106.8681	97.3849	112.5046

Utilization Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.2854	0.4516	0.0000	0.0000	1.0000	275

InputQueue Information
Queue Number 1 Statistics
Queue Length Statistics
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.3651	0.7883	2.0000	0.0000	3.0000	825

Time In Queue Statistics
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
411	44.6585	28.1280	10.0000	10.0000	120.5920

OutputQueue Information
Queue Length Statistics
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.0000	0.0000	0.0000	0.0000	1.0000	823

Time In Queue Statistics
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
411	0.0000	0.0000	0.0000	0.0000	0.0000

<<< O >>>

op1 (a Production Operator)

Utilization Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.1504	0.3575	0.0000	0.0000	1.0000	719

Break Times Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.0000	0.0000	0.0000	0.0000	0.0000	1

Setup Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
164	15.7012	4.0278	15.0000	10.0000	20.0000

Unloading Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
194	25.7990	13.6388	40.0000	10.0000	40.0000

Walking Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
349	0.0000	0.0000	0.0000	0.0000	0.0000

<<< O >>>

op2 (a Production Operator)

Utilization Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.1503	0.3574	0.0000	0.0000	1.0000	939

Break Times Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.0000	0.0000	0.0000	0.0000	0.0000	1

Setup Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
249	14.5382	4.0520	15.0000	10.0000	20.0000

Unloading Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
219	18.0594	11.5537	15.0000	10.0000	40.0000

Walking Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
458	0.0000	0.0000	0.0000	0.0000	0.0000

<<< O >>>

mt1 (a Maintenance Technician)

Utilization Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.1209	0.3260	0.0000	0.0000	1.0000	52

Break Times Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.0000	0.0000	0.0000	0.0000	0.0000	1

Maintenance Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
25	240.0000	0.0000	240.0000	240.0000	240.0000

Walking Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
25	0.0000	0.0000	0.0000	0.0000	0.0000

<<< O >>>

Simulation Output: Run 2 of 10

Calendar Statistics

Event List Length Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
11.5251	0.7770	10.0000	8.0000	16.0000	59414

<<< O >>>

Final Terminator (a Terminator Object)

Time In System Statistics
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
411	900.3112	141.4583	1016.9215	669.0525	1354.7645

<<< O >>>

mach1 (a Single Queue, Multiple Server Processing Object)

Processing Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
138	225.5148	4.9765	236.3496	210.7036	240.8267

Utilization Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.6145	0.4942	1.0000	0.0000	2.0000	277

InputQueue Information
Queue Number 1 Statistics
Queue Length Statistics
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
1.1450	0.9178	0.0000	0.0000	4.0000	828

Time In Queue Statistics
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
414	139.7561	112.1349	20.0000	20.0000	609.1962

OutputQueue Information
Queue Length Statistics
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.4026	0.8539	0.0000	0.0000	3.0000	829

Time In Queue Statistics
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
414	49.0137	29.6838	82.5556	6.2847	185.0050

<<< O >>>

mach2 (a Single Queue, Multiple Server Processing Object)

```
----------------------------------------------------------
Processing Times Information
     Time of initialization = 50000.00
     Current Time           = 100400
Total Obs.   Avg Obs.  Std Dev.   Last Obs.   Min Obs.   Max Obs.
----------   --------  --------   ---------   --------   --------
       143    81.6312   15.0197      8.4468     3.2108    94.5206

Utilization Information
     Time of initialization = 50000.00
     Current Time           = 100400
 Avg Value     Std Dev    Curr Value   Min Value    Max Value   No. Changes
----------  ----------   ----------   ----------   ----------   -----------
    0.2327      0.4226       1.0000       0.0000       1.0000           288

*InputQueue Information*
Queue Number 1 Statistics
Queue Length Statistics
     Time of initialization = 50000.00
     Current Time           = 100400
 Avg Value     Std Dev    Curr Value   Min Value    Max Value   No. Changes
----------  ----------   ----------   ----------   ----------   -----------
    0.4902      0.9559       0.0000       0.0000       3.0000           829

Time In Queue Statistics
     Time of initialization = 50000.00
     Current Time           = 100400
Total Obs.   Avg Obs.  Std Dev.   Last Obs.   Min Obs.   Max Obs.
----------   --------  --------   ---------   --------   --------
       414    59.6743   50.9779     15.8119    15.0000   314.1665

*OutputQueue Information*
Queue Length Statistics
     Time of initialization = 50000.00
     Current Time           = 100400
 Avg Value     Std Dev    Curr Value   Min Value    Max Value   No. Changes
----------  ----------   ----------   ----------   ----------   -----------
    0.4221      0.8695       1.0000       0.0000       3.0000           822

Time In Queue Statistics
     Time of initialization = 50000.00
     Current Time           = 100400
Total Obs.   Avg Obs.  Std Dev.   Last Obs.   Min Obs.   Max Obs.
----------   --------  --------   ---------   --------   --------
       410    51.7065   33.2529     54.0909     4.2483   200.1948

                          <<< O >>>

mach3  (a Single Queue, Multiple Server Processing Object)
----------------------------------------------------------
Processing Times Information
     Time of initialization = 50000.00
     Current Time           = 100400
Total Obs.   Avg Obs.  Std Dev.   Last Obs.   Min Obs.   Max Obs.
----------   --------  --------   ---------   --------   --------
       137   105.0812    2.7326    105.2849    98.4777   113.7522

Utilization Information
     Time of initialization = 50000.00
     Current Time           = 100400
```

```
 Avg Value    Std Dev   Curr Value   Min Value   Max Value  No. Changes
----------  ----------  ----------  ----------  ----------  -----------
    0.2849      0.4514      0.0000      0.0000      1.0000          274

*InputQueue Information*
Queue Number 1 Statistics
Queue Length Statistics
     Time of initialization = 50000.00
     Current Time           = 100400
 Avg Value    Std Dev   Curr Value   Min Value   Max Value  No. Changes
----------  ----------  ----------  ----------  ----------  -----------
    0.3520      0.7748      2.0000      0.0000      3.0000          819

Time In Queue Statistics
     Time of initialization = 50000.00
     Current Time           = 100400
Total Obs.   Avg Obs.  Std Dev.    Last Obs.   Min Obs.   Max Obs.
----------   --------  --------   ---------   --------   --------
       408    43.3103   27.1878     10.0000    10.0000   108.6014

*OutputQueue Information*
Queue Length Statistics
     Time of initialization = 50000.00
     Current Time           = 100400
 Avg Value    Std Dev   Curr Value   Min Value   Max Value  No. Changes
----------  ----------  ----------  ----------  ----------  -----------
    0.0000      0.0000      0.0000      0.0000      1.0000          823

Time In Queue Statistics
     Time of initialization = 50000.00
     Current Time           = 100400
Total Obs.   Avg Obs.  Std Dev.    Last Obs.   Min Obs.   Max Obs.
----------   --------  --------   ---------   --------   --------
       411     0.0000    0.0000      0.0000     0.0000     0.0000

                          <<< O >>>

op1  (a Production Operator)
     -------------------------------------------------------
     Utilization Information
          Time of initialization = 50000.00
          Current Time           = 100400
      Avg Value    Std Dev   Curr Value   Min Value   Max Value  No. Changes
     ----------  ----------  ----------  ----------  ----------  -----------
         0.1500      0.3571      0.0000      0.0000      1.0000          731

     Break Times Information
          Time of initialization = 50000.00
          Current Time           = 100400
      Avg Value    Std Dev   Curr Value   Min Value   Max Value  No. Changes
     ----------  ----------  ----------  ----------  ----------  -----------
         0.0000      0.0000      0.0000      0.0000      0.0000            1

     Setup Times Information
          Time of initialization = 50000.00
          Current Time           = 100400
     Total Obs.   Avg Obs.  Std Dev.    Last Obs.   Min Obs.   Max Obs.
     ----------   --------  --------   ---------   --------   --------
            185    15.8108    4.0233     20.0000    10.0000    20.0000
```

Unloading Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
180	25.7500	13.7868	40.0000	10.0000	40.0000

Walking Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
357	0.0000	0.0000	0.0000	0.0000	0.0000

<<< O >>>

op2 (a Production Operator)

Utilization Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.1503	0.3574	0.0000	0.0000	1.0000	921

Break Times Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.0000	0.0000	0.0000	0.0000	0.0000	1

Setup Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
227	14.3833	4.0263	20.0000	10.0000	20.0000

Unloading Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
232	18.5776	11.7478	15.0000	10.0000	40.0000

Walking Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
448	0.0000	0.0000	0.0000	0.0000	0.0000

<<< O >>>

mt1 (a Maintenance Technician)

Utilization Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.1210	0.3262	0.0000	0.0000	1.0000	52

Break Times Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.0000	0.0000	0.0000	0.0000	0.0000	1

Maintenance Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
25	240.0000	0.0000	240.0000	240.0000	240.0000

Walking Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
25	0.0000	0.0000	0.0000	0.0000	0.0000

<<< O >>>

Simulation Output: Run 3 of 10

Calendar Statistics

Event List Length Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
11.5305	1.0529	10.0000	8.0000	18.0000	59069

<<< O >>>

Final Terminator (a Terminator Object)

Time In System Statistics
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
411	1213.3835	892.7146	1104.3808	681.9816	5261.6763

<<< O >>>

mach1 (a Single Queue, Multiple Server Processing Object)

Processing Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
138	224.4671	4.5741	222.1963	210.5511	236.0649

Utilization Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.6141	0.5162	1.0000	0.0000	2.0000	277

InputQueue Information
Queue Number 1 Statistics
Queue Length Statistics
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
1.2106	0.9329	0.0000	0.0000	6.0000	827

Time In Queue Statistics
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
414	147.8046	167.5484	20.0000	20.0000	2096.4528

OutputQueue Information
Queue Length Statistics
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.4452	0.8922	0.0000	0.0000	3.0000	829

Time In Queue Statistics
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
414	54.1992	34.8076	106.8542	6.2847	200.7505

<<< O >>>

mach2 (a Single Queue, Multiple Server Processing Object)

Processing Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
146	80.6886	16.5659	91.6709	4.8068	93.8753

Utilization Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.2337	0.4232	0.0000	0.0000	1.0000	293

InputQueue Information
Queue Number 1 Statistics
Queue Length Statistics
Time of initialization = 50000.00

Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
2.3620	5.4605	0.0000	0.0000	24.0000	829

Time In Queue Statistics
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
414	287.5486	803.4013	15.0000	15.0000	4353.0741

OutputQueue Information
Queue Length Statistics
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.4610	0.9175	0.0000	0.0000	5.0000	823

Time In Queue Statistics
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
411	56.5308	37.5054	96.3889	3.0210	186.4359

<<< O >>>

mach3 (a Single Queue, Multiple Server Processing Object)

Processing Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
137	105.3352	2.9859	102.3960	98.5788	112.3587

Utilization Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.2867	0.4522	1.0000	0.0000	1.0000	275

InputQueue Information
Queue Number 1 Statistics
Queue Length Statistics
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.4240	0.8814	0.0000	0.0000	5.0000	823

Time In Queue Statistics
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
411	51.9961	34.9490	10.0000	10.0000	173.0086

OutputQueue Information
Queue Length Statistics
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.0000	0.0000	0.0000	0.0000	1.0000	823

Time In Queue Statistics
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
411	0.0000	0.0000	0.0000	0.0000	0.0000

<<< O >>>

op1 (a Production Operator)

Utilization Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.1502	0.3572	1.0000	0.0000	1.0000	754

Break Times Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.0000	0.0000	0.0000	0.0000	0.0000	1

Setup Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
183	15.7104	3.9970	15.0000	10.0000	20.0000

Unloading Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
193	24.3523	13.6156	15.0000	10.0000	40.0000

Walking Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
356	0.0000	0.0000	0.0000	0.0000	0.0000

<<< O >>>

op2 (a Production Operator)

Utilization Information

Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.1505	0.3576	0.0000	0.0000	1.0000	905

Break Times Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.0000	0.0000	0.0000	0.0000	0.0000	1

Setup Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
230	14.4565	4.0773	10.0000	10.0000	20.0000

Unloading Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
220	19.3636	12.2774	15.0000	10.0000	40.0000

Walking Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
425	0.0000	0.0000	0.0000	0.0000	0.0000

<<< O >>>

mt1 (a Maintenance Technician)

Utilization Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.1212	0.3264	0.0000	0.0000	1.0000	52

Break Times Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.0000	0.0000	0.0000	0.0000	0.0000	1

Maintenance Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
25	240.0000	0.0000	240.0000	240.0000	240.0000

Walking Times Information

Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
25	0.0000	0.0000	0.0000	0.0000	0.0000

<<< O >>>

Simulation Output: Run 4 of 10

Calendar Statistics

Event List Length Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
11.5346	0.8264	10.0000	8.0000	17.0000	59592

<<< O >>>

Final Terminator (a Terminator Object)

Time In System Statistics
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
414	1004.0392	381.9140	933.4336	670.1617	3279.9875

<<< O >>>

mach1 (a Single Queue, Multiple Server Processing Object)

Processing Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
137	225.7963	5.1420	217.0870	213.2315	239.3013

Utilization Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.6142	0.4970	1.0000	0.0000	2.0000	276

InputQueue Information
Queue Number 1 Statistics
Queue Length Statistics
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
1.1467	0.9129	0.0000	0.0000	3.0000	827

Time In Queue Statistics
Time of initialization = 50000.00

```
     Current Time          = 100400
Total Obs.   Avg Obs.  Std Dev.   Last Obs.   Min Obs.   Max Obs.
----------   --------  --------   ---------   --------   --------
       414   140.2662  112.8966     20.0000    20.0000   579.7661

*OutputQueue Information*
Queue Length Statistics
     Time of initialization = 50000.00
     Current Time          = 100400
 Avg Value    Std Dev    Curr Value   Min Value    Max Value  No. Changes
----------  ----------  ----------  ----------  ----------  -----------
    0.4301      0.8755      1.0000      0.0000      3.0000          828

Time In Queue Statistics
     Time of initialization = 50000.00
     Current Time          = 100400
Total Obs.   Avg Obs.  Std Dev.   Last Obs.   Min Obs.   Max Obs.
----------   --------  --------   ---------   --------   --------
       413    52.3592   34.5840     17.4665     6.2847   228.2607

                         <<< O >>>

mach2  (a Single Queue, Multiple Server Processing Object)
----------------------------------------------------------
Processing Times Information
     Time of initialization = 50000.00
     Current Time          = 100400
Total Obs.   Avg Obs.  Std Dev.   Last Obs.   Min Obs.   Max Obs.
----------   --------  --------   ---------   --------   --------
       142    81.9469   13.6789     87.7924     3.7377    91.8364

Utilization Information
     Time of initialization = 50000.00
     Current Time          = 100400
 Avg Value    Std Dev    Curr Value   Min Value    Max Value  No. Changes
----------  ----------  ----------  ----------  ----------  -----------
    0.2309      0.4214      0.0000      0.0000      1.0000          285

*InputQueue Information*
Queue Number 1 Statistics
Queue Length Statistics
     Time of initialization = 50000.00
     Current Time          = 100400
 Avg Value    Std Dev    Curr Value   Min Value    Max Value  No. Changes
----------  ----------  ----------  ----------  ----------  -----------
    1.2104      3.1134      2.0000      0.0000     21.0000          825

Time In Queue Statistics
     Time of initialization = 50000.00
     Current Time          = 100400
Total Obs.   Avg Obs.  Std Dev.   Last Obs.   Min Obs.   Max Obs.
----------   --------  --------   ---------   --------   --------
       411   148.2856  363.5447     15.0000    15.0000  2323.4326


*OutputQueue Information*
Queue Length Statistics
     Time of initialization = 50000.00
     Current Time          = 100400
```

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.4677	0.9302	0.0000	0.0000	5.0000	823

Time In Queue Statistics
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
411	57.3547	37.5651	94.3125	3.1593	216.8800

<<< O >>>

mach3 (a Single Queue, Multiple Server Processing Object)

Processing Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
138	104.7603	3.0199	103.0480	94.7244	112.9849

Utilization Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.2853	0.4516	0.0000	0.0000	1.0000	276

InputQueue Information
Queue Number 1 Statistics
Queue Length Statistics
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.3823	0.8258	0.0000	0.0000	5.0000	823

Time In Queue Statistics
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
411	46.8822	31.1435	10.0000	10.0000	165.9957

OutputQueue Information
Queue Length Statistics
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.0000	0.0000	0.0000	0.0000	1.0000	829

Time In Queue Statistics
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
414	0.0000	0.0000	0.0000	0.0000	0.0000

<<< O >>>

op1 (a Production Operator)

Utilization Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.1502	0.3573	0.0000	0.0000	1.0000	781

Break Times Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.0000	0.0000	0.0000	0.0000	0.0000	1

Setup Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
207	15.8213	3.9783	20.0000	10.0000	20.0000

Unloading Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
180	23.8611	13.5039	40.0000	10.0000	40.0000

Walking Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
377	0.0000	0.0000	0.0000	0.0000	0.0000

<<< O >>>

op2 (a Production Operator)

Utilization Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.1499	0.3569	0.0000	0.0000	1.0000	876

Break Times Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.0000	0.0000	0.0000	0.0000	0.0000	1

Setup Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
205	14.1951	4.0476	20.0000	10.0000	20.0000

Unloading Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
232	19.9138	12.6042	10.0000	10.0000	40.0000

Walking Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
420	0.0000	0.0000	0.0000	0.0000	0.0000

<<< O >>>

mt1 (a Maintenance Technician)

Utilization Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.1238	0.3294	0.0000	0.0000	1.0000	53

Break Times Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.0000	0.0000	0.0000	0.0000	0.0000	1

Maintenance Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
26	240.0000	0.0000	240.0000	240.0000	240.0000

Walking Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
26	0.0000	0.0000	0.0000	0.0000	0.0000

<<< O >>>

Simulation Output: Run 5 of 10

Calendar Statistics

Event List Length Information

```
     Time of initialization = 50000.00
     Current Time           = 100400
 Avg Value    Std Dev   Curr Value   Min Value   Max Value  No. Changes
----------  ----------  ----------  ----------  ----------  -----------
   11.5349      0.8165     10.0000      8.0000     16.0000        59712

                             <<< O >>>

Final Terminator  (a Terminator Object)
---------------------------------------
    Time In System Statistics
         Time of initialization = 50000.00
         Current Time           = 100400
    Total Obs.  Avg Obs.  Std Dev.   Last Obs.   Min Obs.   Max Obs.
    ----------  --------  --------  ---------   --------   --------
           411  927.1840  154.7430  1319.7251   654.7484  1426.5860

                             <<< O >>>

    mach1  (a Single Queue, Multiple Server Processing Object)
    ----------------------------------------------------------
    Processing Times Information
         Time of initialization = 50000.00
         Current Time           = 100400
    Total Obs.  Avg Obs.  Std Dev.   Last Obs.   Min Obs.   Max Obs.
    ----------  --------  --------  ---------   --------   --------
           138  224.8062    5.6867   227.7368   207.8740   241.4385

    Utilization Information
         Time of initialization = 50000.00
         Current Time           = 100400
     Avg Value    Std Dev   Curr Value   Min Value   Max Value  No. Changes
    ----------  ----------  ----------  ----------  ----------  -----------
        0.6130      0.4974      1.0000      0.0000      2.0000          277

    *InputQueue Information*
    Queue Number 1 Statistics
    Queue Length Statistics
         Time of initialization = 50000.00
         Current Time           = 100400
     Avg Value    Std Dev   Curr Value   Min Value   Max Value  No. Changes
    ----------  ----------  ----------  ----------  ----------  -----------
        1.1959      0.8952      0.0000      0.0000      3.0000          829

    Time In Queue Statistics
         Time of initialization = 50000.00
         Current Time           = 100400
    Total Obs.  Avg Obs.  Std Dev.   Last Obs.   Min Obs.   Max Obs.
    ----------  --------  --------  ---------   --------   --------
           414  145.5900  115.9626    20.0000    20.0000   614.4577

    *OutputQueue Information*

    Queue Length Statistics
         Time of initialization = 50000.00
         Current Time           = 100400
     Avg Value    Std Dev   Curr Value   Min Value   Max Value  No. Changes
    ----------  ----------  ----------  ----------  ----------  -----------
        0.4264      0.8640      0.0000      0.0000      3.0000          829
```

Time In Queue Statistics
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
414	51.9150	33.4772	68.0629	4.1455	224.6209

<<< O >>>

mach2 (a Single Queue, Multiple Server Processing Object)

Processing Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
146	80.6094	16.8098	87.6916	4.3322	93.8753

Utilization Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.2343	0.4236	1.0000	0.0000	1.0000	294

InputQueue Information
Queue Number 1 Statistics
Queue Length Statistics
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.5150	0.9637	0.0000	0.0000	3.0000	832

Time In Queue Statistics
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
417	63.6142	57.2877	15.0000	15.0000	346.7526

OutputQueue Information
Queue Length Statistics
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.4544	0.9323	0.0000	0.0000	6.0000	829

Time In Queue Statistics
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
414	55.3231	40.9759	118.1875	8.6173	247.2792

<<< O >>>

mach3 (a Single Queue, Multiple Server Processing Object)

```
Processing Times Information
     Time of initialization = 50000.00
     Current Time           = 100400
Total Obs.   Avg Obs.  Std Dev.   Last Obs.   Min Obs.   Max Obs.
----------   --------  --------   ---------   --------   --------
       138   104.9093    2.8081    106.7548    99.6009   113.7705

Utilization Information
     Time of initialization = 50000.00
     Current Time           = 100400
 Avg Value    Std Dev   Curr Value   Min Value   Max Value  No. Changes
----------  ----------  ----------  ----------  ----------  -----------
    0.2873      0.4525      0.0000      0.0000      1.0000          277

*InputQueue Information*
Queue Number 1 Statistics
Queue Length Statistics
     Time of initialization = 50000.00
     Current Time           = 100400
 Avg Value    Std Dev   Curr Value   Min Value   Max Value  No. Changes
----------  ----------  ----------  ----------  ----------  -----------
    0.3726      0.8026      0.0000      0.0000      3.0000          829

Time In Queue Statistics
     Time of initialization = 50000.00
     Current Time           = 100400
Total Obs.   Avg Obs.  Std Dev.   Last Obs.   Min Obs.   Max Obs.
----------   --------  --------   ---------   --------   --------
       414    45.3567   27.7977     10.0000    10.0000   106.5051

*OutputQueue Information*
Queue Length Statistics
     Time of initialization = 50000.00
     Current Time           = 100400
 Avg Value    Std Dev   Curr Value   Min Value   Max Value  No. Changes
----------  ----------  ----------  ----------  ----------  -----------
    0.0000      0.0000      0.0000      0.0000      1.0000          823

Time In Queue Statistics
     Time of initialization = 50000.00
     Current Time           = 100400
Total Obs.   Avg Obs.  Std Dev.   Last Obs.   Min Obs.   Max Obs.
----------   --------  --------   ---------   --------   --------
       411     0.0000    0.0000      0.0000     0.0000     0.0000

                          <<< O >>>

op1  (a Production Operator)
     -------------------------------------------------------
     Utilization Information
          Time of initialization = 50000.00
          Current Time           = 100400
      Avg Value    Std Dev   Curr Value   Min Value   Max Value  No. Changes
     ----------  ----------  ----------  ----------  ----------  -----------
         0.1508      0.3578      0.0000      0.0000      1.0000          729

     Break Times Information
          Time of initialization = 50000.00
          Current Time           = 100400
      Avg Value    Std Dev   Curr Value   Min Value   Max Value  No. Changes
```

0.0000	0.0000	0.0000	0.0000	0.0000	1

Setup Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
169	15.3254	4.0142	20.0000	10.0000	20.0000

Unloading Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
195	25.6923	13.5334	40.0000	10.0000	40.0000

Walking Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
352	0.0000	0.0000	0.0000	0.0000	0.0000

<<< O >>>

op2 (a Production Operator)

Utilization Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.1507	0.3577	1.0000	0.0000	1.0000	930

Break Times Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.0000	0.0000	0.0000	0.0000	0.0000	1

Setup Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
246	14.7764	4.1220	15.0000	10.0000	20.0000

Unloading Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
219	18.0822	11.6907	10.0000	10.0000	40.0000

Walking Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs. Avg Obs. Std Dev. Last Obs. Min Obs. Max Obs.

451	0.0000	0.0000	0.0000	0.0000	0.0000

<<< O >>>

mt1 (a Maintenance Technician)

Utilization Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.1197	0.3247	0.0000	0.0000	1.0000	52

Break Times Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.0000	0.0000	0.0000	0.0000	0.0000	1

Maintenance Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
25	240.0000	0.0000	240.0000	240.0000	240.0000

Walking Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
25	0.0000	0.0000	0.0000	0.0000	0.0000

<<< O >>>

Simulation Output: Run 6 of 10

Calendar Statistics

Event List Length Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
11.5252	0.7841	11.0000	9.0000	16.0000	59385

<<< O >>>

Final Terminator (a Terminator Object)

Time In System Statistics
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
411	914.7885	146.1406	916.1246	664.6458	1397.2215

<<< O >>>

Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.2316	0.4218	0.0000	0.0000	1.0000	291

InputQueue Information
Queue Number 1 Statistics
Queue Length Statistics
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.4875	0.9635	2.0000	0.0000	6.0000	825

Time In Queue Statistics
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
411	59.6685	50.0342	15.0000	15.0000	293.7926

OutputQueue Information
Queue Length Statistics
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.4416	0.9043	0.0000	0.0000	5.0000	823

Time In Queue Statistics
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
411	54.1572	39.6163	114.7738	3.7801	205.6120

<<< O >>>

mach3 (a Single Queue, Multiple Server Processing Object)

Processing Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
137	105.2697	3.4107	104.4383	95.1950	113.7883

Utilization Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.2866	0.4522	1.0000	0.0000	1.0000	275

InputQueue Information
Queue Number 1 Statistics
Queue Length Statistics
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.3577	0.7830	0.0000	0.0000	3.0000	823

Time In Queue Statistics
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
411	43.8624	27.7115	10.0000	10.0000	117.2639

OutputQueue Information
Queue Length Statistics
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.0000	0.0000	0.0000	0.0000	1.0000	823

Time In Queue Statistics
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
411	0.0000	0.0000	0.0000	0.0000	0.0000

<<< O >>>

op1 (a Production Operator)

Utilization Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.1498	0.3569	0.0000	0.0000	1.0000	730

Break Times Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.0000	0.0000	0.0000	0.0000	0.0000	1

Setup Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
178	15.8427	4.0293	20.0000	10.0000	20.0000

Unloading Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
185	25.5135	13.8069	40.0000	10.0000	40.0000

Walking Times Information
Time of initialization = 50000.00

Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
354	0.0000	0.0000	0.0000	0.0000	0.0000

<<< O >>>

op2 (a Production Operator)

Utilization Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.1494	0.3565	0.0000	0.0000	1.0000	919

Break Times Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.0000	0.0000	0.0000	0.0000	0.0000	1

Setup Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
233	14.3562	4.0223	10.0000	10.0000	20.0000

Unloading Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
226	18.5177	11.6864	15.0000	10.0000	40.0000

Walking Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
449	0.0000	0.0000	0.0000	0.0000	0.0000

<<< O >>>

mt1 (a Maintenance Technician)

Utilization Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.1231	0.3285	1.0000	0.0000	1.0000	52

Break Times Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes

0.0000	0.0000	0.0000	0.0000	0.0000	1

Maintenance Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
26	240.0000	0.0000	240.0000	240.0000	240.0000

Walking Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
26	0.0000	0.0000	0.0000	0.0000	0.0000

<<< O >>>

Simulation Output: Run 7 of 10

Calendar Statistics

Event List Length Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
11.5355	0.7845	10.0000	8.0000	16.0000	60051

<<< O >>>

Final Terminator (a Terminator Object)

Time In System Statistics
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
408	915.1806	146.8250	1068.1608	654.7021	1470.4904

<<< O >>>

mach1 (a Single Queue, Multiple Server Processing Object)

Processing Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
137	224.5105	5.0350	229.7873	209.7700	240.8677

Utilization Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.6118	0.4900	1.0000	0.0000	2.0000	276

InputQueue Information
Queue Number 1 Statistics

Queue Length Statistics
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
1.1823	0.8940	0.0000	0.0000	4.0000	827

Time In Queue Statistics
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
414	144.8513	113.3572	20.0000	20.0000	393.4233

OutputQueue Information
Queue Length Statistics
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.4197	0.8704	0.0000	0.0000	3.0000	825

Time In Queue Statistics
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
413	51.4394	30.8045	131.5262	6.2847	187.5198

<<< O >>>

mach2 (a Single Queue, Multiple Server Processing Object)

Processing Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
142	81.7015	11.8293	81.3081	16.7851	92.5509

Utilization Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.2313	0.4217	1.0000	0.0000	1.0000	286

InputQueue Information
Queue Number 1 Statistics
Queue Length Statistics
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.5548	1.0153	0.0000	0.0000	3.0000	828

Time In Queue Statistics
Time of initialization = 50000.00
Current Time = 100400

Total Obs. Avg Obs. Std Dev. Last Obs. Min Obs. Max Obs.

414	67.5633	62.2037	15.0000	15.0000	328.7178

OutputQueue Information
Queue Length Statistics
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.4397	0.9098	0.0000	0.0000	6.0000	823

Time In Queue Statistics
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
411	53.9251	39.1769	87.1319	7.6372	230.3252

<<< O >>>

mach3 (a Single Queue, Multiple Server Processing Object)

Processing Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
136	104.8149	3.0295	104.2399	98.4246	115.4690

Utilization Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.2838	0.4508	1.0000	0.0000	1.0000	274

InputQueue Information
Queue Number 1 Statistics
Queue Length Statistics
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.3700	0.8017	0.0000	0.0000	3.0000	823

Time In Queue Statistics
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
411	45.3764	28.0838	10.0000	10.0000	120.7917

OutputQueue Information
Queue Length Statistics
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.0000	0.0000	0.0000	0.0000	1.0000	817

Time In Queue Statistics
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
408	0.0000	0.0000	0.0000	0.0000	0.0000

<<< O >>>

op1 (a Production Operator)

Utilization Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.1500	0.3571	0.0000	0.0000	1.0000	785

Break Times Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.0000	0.0000	0.0000	0.0000	0.0000	1

Setup Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
208	15.6010	4.0824	20.0000	10.0000	20.0000

Unloading Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
182	23.7088	13.5070	40.0000	10.0000	40.0000

Walking Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
376	0.0000	0.0000	0.0000	0.0000	0.0000

<<< O >>>

op2 (a Production Operator)

Utilization Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.1495	0.3566	0.0000	0.0000	1.0000	867

Break Times Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.0000	0.0000	0.0000	0.0000	0.0000	1

Setup Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
205	14.4146	4.0096	10.0000	10.0000	20.0000

Unloading Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
228	20.0877	12.6453	15.0000	10.0000	40.0000

Walking Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
423	0.0000	0.0000	0.0000	0.0000	0.0000

<<< O >>>

mt1 (a Maintenance Technician)

Utilization Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.1230	0.3285	0.0000	0.0000	1.0000	52

Break Times Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.0000	0.0000	0.0000	0.0000	0.0000	1

Maintenance Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
25	240.0000	0.0000	240.0000	240.0000	240.0000

Walking Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
25	0.0000	0.0000	0.0000	0.0000	0.0000

<<< O >>>

Simulation Output: Run 8 of 10

Calendar Statistics

Event List Length Information

Time of initialization = 50000.00

Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
11.5579	0.8178	10.0000	8.0000	16.0000	60818

<<< O >>>

Final Terminator (a Terminator Object)

Time In System Statistics

Time of initialization = 50000.00

Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
411	939.4955	155.6871	1123.2842	667.7130	1465.1146

<<< O >>>

mach1 (a Single Queue, Multiple Server Processing Object)

Processing Times Information

Time of initialization = 50000.00

Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
137	224.6608	4.8529	223.6444	213.5089	240.0063

Utilization Information

Time of initialization = 50000.00

Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.6117	0.5034	1.0000	0.0000	2.0000	276

InputQueue Information

Queue Number 1 Statistics

Queue Length Statistics

Time of initialization = 50000.00

Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
1.1919	0.9082	0.0000	0.0000	4.0000	827

Time In Queue Statistics

Time of initialization = 50000.00

Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
414	145.6457	121.4403	20.0000	20.0000	674.9038

OutputQueue Information

Queue Length Statistics

Time of initialization = 50000.00

Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes

0.4590	0.8972	0.0000	0.0000	4.0000	829

Time In Queue Statistics
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
414	55.8819	37.6252	90.4309	6.2847	270.1484

<<< O >>>

mach2 (a Single Queue, Multiple Server Processing Object)

Processing Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
145	80.5184	15.9304	57.8823	5.8087	92.8529

Utilization Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.2327	0.4226	1.0000	0.0000	1.0000	292

InputQueue Information
Queue Number 1 Statistics
Queue Length Statistics
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.5595	1.0019	0.0000	0.0000	4.0000	829

Time In Queue Statistics
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
414	68.1177	56.6465	34.8803	15.0000	337.5380

OutputQueue Information
Queue Length Statistics
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.4843	0.9516	1.0000	0.0000	6.0000	822

Time In Queue Statistics
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
410	59.3643	40.8391	50.1250	9.6181	232.7553

<<< O >>>

```
mach3  (a Single Queue, Multiple Server Processing Object)
-----------------------------------------------------------
Processing Times Information
     Time of initialization = 50000.00
     Current Time           = 100400
Total Obs.   Avg Obs.  Std Dev.   Last Obs.   Min Obs.   Max Obs.
----------   --------  --------   ---------   --------   --------
       137   105.1257    2.7315    101.2841    99.2704   111.6401

Utilization Information
     Time of initialization = 50000.00
     Current Time           = 100400
 Avg Value    Std Dev    Curr Value   Min Value   Max Value  No. Changes
----------  ----------  ----------  ----------  ----------  -----------
    0.2844      0.4511      0.0000      0.0000      1.0000          274

*InputQueue Information*
Queue Number 1 Statistics
Queue Length Statistics
     Time of initialization = 50000.00
     Current Time           = 100400
 Avg Value    Std Dev    Curr Value   Min Value   Max Value  No. Changes
----------  ----------  ----------  ----------  ----------  -----------
    0.3739      0.7958      2.0000      0.0000      3.0000          819

Time In Queue Statistics
     Time of initialization = 50000.00
     Current Time           = 100400
Total Obs.   Avg Obs.  Std Dev.   Last Obs.   Min Obs.   Max Obs.
----------   --------  --------   ---------   --------   --------
       408    46.0547   29.2626     10.0000    10.0000   136.0120

*OutputQueue Information*
Queue Length Statistics
     Time of initialization = 50000.00
     Current Time           = 100400
 Avg Value    Std Dev    Curr Value   Min Value   Max Value  No. Changes
----------  ----------  ----------  ----------  ----------  -----------
    0.0000      0.0000      0.0000      0.0000      1.0000          823

Time In Queue Statistics
     Time of initialization = 50000.00
     Current Time           = 100400
Total Obs.   Avg Obs.  Std Dev.   Last Obs.   Min Obs.   Max Obs.
----------   --------  --------   ---------   --------   --------
       411     0.0000    0.0000      0.0000     0.0000     0.0000

                          <<< O >>>

op1  (a Production Operator)
     -------------------------------------------------------
     Utilization Information
          Time of initialization = 50000.00
          Current Time           = 100400
      Avg Value    Std Dev    Curr Value   Min Value   Max Value  No. Changes
     ----------  ----------  ----------  ----------  ----------  -----------
         0.1503      0.3574      0.0000      0.0000      1.0000          738

     Break Times Information
```

Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.0000	0.0000	0.0000	0.0000	0.0000	1

Setup Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
191	15.7592	4.0814	20.0000	10.0000	20.0000

Unloading Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
176	25.7386	13.6285	40.0000	10.0000	40.0000

Walking Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
352	0.0000	0.0000	0.0000	0.0000	0.0000

<<< O >>>

op2 (a Production Operator)

Utilization Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.1499	0.3570	0.0000	0.0000	1.0000	915

Break Times Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.0000	0.0000	0.0000	0.0000	0.0000	1

Setup Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
221	14.3891	3.9844	15.0000	10.0000	20.0000

Unloading Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
235	18.6170	11.9070	15.0000	10.0000	40.0000

Walking Times Information

Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
444	0.0000	0.0000	0.0000	0.0000	0.0000

<<< O >>>

mt1 (a Maintenance Technician)

Utilization Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.1238	0.3294	0.0000	0.0000	1.0000	53

Break Times Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.0000	0.0000	0.0000	0.0000	0.0000	1

Maintenance Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
26	240.0000	0.0000	240.0000	240.0000	240.0000

Walking Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
26	0.0000	0.0000	0.0000	0.0000	0.0000

<<< O >>>

Simulation Output: Run 9 of 10

Calendar Statistics

Event List Length Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
11.5366	0.7792	9.0000	9.0000	16.0000	59684

<<< O >>>

Final Terminator (a Terminator Object)

Time In System Statistics
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.

411	907.8215	137.0574	1014.5751	667.8733	1374.1016

<<< O >>>

mach1 (a Single Queue, Multiple Server Processing Object)

Processing Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
138	224.9062	5.0889	228.8878	209.7873	236.8836

Utilization Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.6127	0.4893	0.0000	0.0000	2.0000	276

InputQueue Information
Queue Number 1 Statistics
Queue Length Statistics
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
1.1640	0.9055	2.0000	0.0000	4.0000	824

Time In Queue Statistics
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
411	142.2638	113.1625	20.0000	20.0000	413.3552

OutputQueue Information
Queue Length Statistics
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.4172	0.8618	0.0000	0.0000	3.0000	829

Time In Queue Statistics
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
414	50.7917	29.3263	67.1319	3.8784	144.3750

<<< O >>>

mach2 (a Single Queue, Multiple Server Processing Object)

Processing Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.

142	81.8781	13.3409	83.5355	2.2556	93.2529

Utilization Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.2308	0.4213	1.0000	0.0000	1.0000	286

InputQueue Information
Queue Number 1 Statistics
Queue Length Statistics
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.5172	0.9743	0.0000	0.0000	3.0000	829

Time In Queue Statistics
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
414	62.9687	54.4617	15.0000	15.0000	293.4539

OutputQueue Information
Queue Length Statistics
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.4255	0.8722	0.0000	0.0000	4.0000	826

Time In Queue Statistics
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
414	51.8490	32.7934	142.8346	4.2946	185.5996

<<< O >>>

mach3 (a Single Queue, Multiple Server Processing Object)

Processing Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
137	104.8609	2.9061	106.6260	98.9840	113.3479

Utilization Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.2867	0.4522	1.0000	0.0000	1.0000	276

InputQueue Information
Queue Number 1 Statistics

Queue Length Statistics
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.3695	0.7981	0.0000	0.0000	3.0000	829

Time In Queue Statistics
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
414	44.9832	28.2291	10.0000	10.0000	117.7168

OutputQueue Information
Queue Length Statistics
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.0000	0.0000	0.0000	0.0000	1.0000	823

Time In Queue Statistics
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
411	0.0000	0.0000	0.0000	0.0000	0.0000

<<< O >>>

op1 (a Production Operator)

Utilization Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.1501	0.3572	0.0000	0.0000	1.0000	791

Break Times Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.0000	0.0000	0.0000	0.0000	0.0000	1

Setup Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
210	15.5238	3.9388	15.0000	10.0000	20.0000

Unloading Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
184	23.3967	13.4899	15.0000	10.0000	40.0000

Walking Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
381	0.0000	0.0000	0.0000	0.0000	0.0000

<<< O >>>

op2 (a Production Operator)

Utilization Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.1502	0.3573	0.0000	0.0000	1.0000	863

Break Times Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.0000	0.0000	0.0000	0.0000	0.0000	1

Setup Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
203	14.4335	4.1684	15.0000	10.0000	20.0000

Unloading Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
228	20.3509	12.7449	40.0000	10.0000	40.0000

Walking Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
422	0.0000	0.0000	0.0000	0.0000	0.0000

<<< O >>>

mt1 (a Maintenance Technician)

Utilization Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.1234	0.3289	0.0000	0.0000	1.0000	52

Break Times Information
Time of initialization = 50000.00

```
     Current Time          = 100400
 Avg Value    Std Dev   Curr Value   Min Value   Max Value  No. Changes
----------  ----------  ----------  ----------  ----------  -----------
    0.0000      0.0000      0.0000      0.0000      0.0000            1

Maintenance Times Information
     Time of initialization = 50000.00
     Current Time          = 100400
Total Obs.   Avg Obs.  Std Dev.   Last Obs.   Min Obs.   Max Obs.
----------   --------  --------   ---------   --------   --------
        25   240.0000    0.0000    240.0000   240.0000   240.0000

Walking Times Information
     Time of initialization = 50000.00
     Current Time          = 100400
Total Obs.   Avg Obs.  Std Dev.   Last Obs.   Min Obs.   Max Obs.
----------   --------  --------   ---------   --------   --------
        25     0.0000    0.0000      0.0000     0.0000     0.0000

                        <<< O >>>

Simulation Output: Run 10 of 10

Calendar Statistics
-------------------
     Event List Length Information
          Time of initialization = 50000.00
          Current Time          = 100400
      Avg Value    Std Dev   Curr Value   Min Value   Max Value  No. Changes
     ----------  ----------  ----------  ----------  ----------  -----------
        11.5426      0.8474      9.0000      8.0000     17.0000        59868

                        <<< O >>>

 Final Terminator  (a Terminator Object)
---------------------------------------
     Time In System Statistics
          Time of initialization = 50000.00
          Current Time          = 100400
     Total Obs.   Avg Obs.  Std Dev.   Last Obs.   Min Obs.   Max Obs.
     ----------   --------  --------   ---------   --------   --------
            417  1011.3301  387.2228    955.2777   674.0765  3266.5366

                        <<< O >>>

     mach1  (a Single Queue, Multiple Server Processing Object)
     ----------------------------------------------------------
     Processing Times Information
          Time of initialization = 50000.00
          Current Time          = 100400
     Total Obs.   Avg Obs.  Std Dev.   Last Obs.   Min Obs.   Max Obs.
     ----------   --------  --------   ---------   --------   --------
            138   225.8426    4.7111    218.4941   213.6032   235.5445

     Utilization Information
          Time of initialization = 50000.00
          Current Time          = 100400
      Avg Value    Std Dev   Curr Value   Min Value   Max Value  No. Changes
     ----------  ----------  ----------  ----------  ----------  -----------
         0.6150      0.4951      0.0000      0.0000      2.0000          276
```

```
*InputQueue Information*
Queue Number 1 Statistics
Queue Length Statistics
     Time of initialization = 50000.00
     Current Time           = 100400
 Avg Value    Std Dev   Curr Value   Min Value   Max Value  No. Changes
----------  ----------  ----------  ----------  ----------  -----------
    1.1473      0.8995      2.0000      0.0000      4.0000          824

Time In Queue Statistics
     Time of initialization = 50000.00
     Current Time           = 100400
Total Obs.  Avg Obs.  Std Dev.   Last Obs.   Min Obs.   Max Obs.
----------  --------  --------  ---------   --------   --------
       411  140.5161  113.0738    20.0000    20.0000   405.5980

*OutputQueue Information*
Queue Length Statistics
     Time of initialization = 50000.00
     Current Time           = 100400
 Avg Value    Std Dev   Curr Value   Min Value   Max Value  No. Changes
----------  ----------  ----------  ----------  ----------  -----------
    0.4532      0.8921      0.0000      0.0000      3.0000          829

Time In Queue Statistics
     Time of initialization = 50000.00
     Current Time           = 100400
Total Obs.  Avg Obs.  Std Dev.   Last Obs.   Min Obs.   Max Obs.
----------  --------  --------  ---------   --------   --------
       414   55.1770   36.5488    67.1319     3.5152   261.8082

                         <<< 0 >>>

mach2  (a Single Queue, Multiple Server Processing Object)
----------------------------------------------------------
Processing Times Information
     Time of initialization = 50000.00
     Current Time           = 100400
Total Obs.  Avg Obs.  Std Dev.   Last Obs.   Min Obs.   Max Obs.
----------  --------  --------  ---------   --------   --------
       140   83.2485    9.7599    86.8753    23.5535    94.7899

Utilization Information
     Time of initialization = 50000.00
     Current Time           = 100400
 Avg Value    Std Dev   Curr Value   Min Value   Max Value  No. Changes
----------  ----------  ----------  ----------  ----------  -----------
    0.2312      0.4216      0.0000      0.0000      1.0000          281

*InputQueue Information*
Queue Number 1 Statistics
Queue Length Statistics
     Time of initialization = 50000.00
     Current Time           = 100400
 Avg Value    Std Dev   Curr Value   Min Value   Max Value  No. Changes
----------  ----------  ----------  ----------  ----------  -----------
    1.2909      3.0941      2.0000      0.0000     21.0000          825

Time In Queue Statistics
```

Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
411	158.1215	360.6398	15.0000	15.0000	2339.7185

OutputQueue Information
Queue Length Statistics
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.4786	0.9328	0.0000	0.0000	5.0000	829

Time In Queue Statistics
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
414	58.2622	37.4594	82.1875	5.4575	209.4129

<<< O >>>

mach3 (a Single Queue, Multiple Server Processing Object)

Processing Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
139	104.8972	2.9366	103.0117	98.0525	113.0393

Utilization Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.2873	0.4525	0.0000	0.0000	1.0000	278

InputQueue Information
Queue Number 1 Statistics
Queue Length Statistics
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.4113	0.8722	0.0000	0.0000	6.0000	829

Time In Queue Statistics
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
414	50.0722	35.1901	10.0000	10.0000	211.9616

OutputQueue Information
Queue Length Statistics
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes

0.0000	0.0000	0.0000	0.0000	1.0000	835

Time In Queue Statistics
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
417	0.0000	0.0000	0.0000	0.0000	0.0000

<<< O >>>

op1 (a Production Operator)

Utilization Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.1500	0.3571	0.0000	0.0000	1.0000	801

Break Times Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.0000	0.0000	0.0000	0.0000	0.0000	1

Setup Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
202	15.9158	3.9622	10.0000	10.0000	20.0000

Unloading Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
195	22.2821	12.8552	10.0000	10.0000	40.0000

Walking Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
379	0.0000	0.0000	0.0000	0.0000	0.0000

<<< O >>>

op2 (a Production Operator)

Utilization Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.1505	0.3576	0.0000	0.0000	1.0000	860

Break Times Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.0000	0.0000	0.0000	0.0000	0.0000	1

Setup Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
210	14.0952	4.0203	10.0000	10.0000	20.0000

Unloading Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
219	21.0959	13.4073	40.0000	10.0000	40.0000

Walking Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
410	0.0000	0.0000	0.0000	0.0000	0.0000

<<< O >>>

mt1 (a Maintenance Technician)

Utilization Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.1226	0.3280	1.0000	0.0000	1.0000	52

Break Times Information
Time of initialization = 50000.00
Current Time = 100400

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.0000	0.0000	0.0000	0.0000	0.0000	1

Maintenance Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
26	240.0000	0.0000	240.0000	240.0000	240.0000

Walking Times Information
Time of initialization = 50000.00
Current Time = 100400

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
26	0.0000	0.0000	0.0000	0.0000	0.0000

Appendix E: Representative IASE Simulation Result for Case Study 2

Calendar Statistics

Event List Length Information
Time of initialization = 131040.00
Current Time = 262080

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
14.2998	1.6632	12.0000	9.0000	20.0000	309401

<<< O >>>

Final Terminator (a Terminator Object)

Time In System Statistics
Time of initialization = 131040.00
Current Time = 262080

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
971	3351.6612	1940.4875	2459.3889	990.0208	15953.4167

<<< O >>>

mach1 (a Single Queue, Multiple Server Processing Object)

Processing Times Information
Time of initialization = 131040.00
Current Time = 262080

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
634	247.6183	12.9316	255.0000	225.0000	255.0000

Utilization Information
Time of initialization = 131040.00
Current Time = 262080

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
1.1976	0.7031	0.0000	0.0000	2.0000	1268

InputQueue Information
Queue Number 1 Statistics
Queue Length Statistics
Time of initialization = 131040.00
Current Time = 262080

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
4.9139	3.4787	7.0000	0.0000	21.0000	3800

Time In Queue Statistics
Time of initialization = 131040.00
Current Time = 262080

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
1899	338.1708	344.5376	21.5417	20.0000	7438.8681

```
*OutputQueue Information*
Queue Length Statistics
     Time of initialization = 131040.00
     Current Time           = 262080
 Avg Value     Std Dev    Curr Value    Min Value    Max Value  No. Changes
----------  ----------  ----------  ----------  ----------  -----------
    1.3291      1.6528      0.0000      0.0000     12.0000         3807

Time In Queue Statistics
     Time of initialization = 131040.00
     Current Time           = 262080
Total Obs.   Avg Obs.  Std Dev.   Last Obs.   Min Obs.   Max Obs.
----------   --------  --------   ---------   --------   --------
      1904    91.5525   85.6032     96.6736     3.2917   624.0556

                        <<< O >>>

mach2  (a Single Queue, Multiple Server Processing Object)
----------------------------------------------------------
Processing Times Information
     Time of initialization = 131040.00
     Current Time           = 262080
Total Obs.   Avg Obs.  Std Dev.   Last Obs.   Min Obs.   Max Obs.
----------   --------  --------   ---------   --------   --------
       636    44.5912    9.0342     50.0000     1.7569    50.0000

Utilization Information
     Time of initialization = 131040.00
     Current Time           = 262080
 Avg Value     Std Dev    Curr Value    Min Value    Max Value  No. Changes
----------  ----------  ----------  ----------  ----------  -----------
    0.2164      0.4246      0.0000      0.0000      2.0000         1273

*InputQueue Information*
Queue Number 1 Statistics
Queue Length Statistics
     Time of initialization = 131040.00
     Current Time           = 262080
 Avg Value     Std Dev    Curr Value    Min Value    Max Value  No. Changes
----------  ----------  ----------  ----------  ----------  -----------
    4.2406      8.1567      1.0000      0.0000     35.0000         3804

Time In Queue Statistics
     Time of initialization = 131040.00
     Current Time           = 262080
Total Obs.   Avg Obs.  Std Dev.   Last Obs.   Min Obs.   Max Obs.
----------   --------  --------   ---------   --------   --------
      1902   292.2121 1173.8432     36.5069    15.0000 10736.5486

*OutputQueue Information*
Queue Length Statistics
     Time of initialization = 131040.00
     Current Time           = 262080
 Avg Value     Std Dev    Curr Value    Min Value    Max Value  No. Changes
----------  ----------  ----------  ----------  ----------  -----------
    1.4114      2.5571      3.0000      0.0000     23.0000         3802

Time In Queue Statistics
```

```
     Time of initialization = 131040.00
     Current Time           = 262080
Total Obs.   Avg Obs.  Std Dev.    Last Obs.   Min Obs.   Max Obs.
----------   --------  --------    ---------   --------   --------
      1899    97.2198  101.7217      45.2917     3.3889   682.6528

                              <<< O >>>

mach3  (a Single Queue, Multiple Server Processing Object)
----------------------------------------------------------
Processing Times Information
     Time of initialization = 131040.00
     Current Time           = 262080
Total Obs.   Avg Obs.  Std Dev.    Last Obs.   Min Obs.   Max Obs.
----------   --------  --------    ---------   --------   --------
       645    18.9302   17.9614      10.0000    10.0000    55.0000

Utilization Information
     Time of initialization = 131040.00
     Current Time           = 262080
 Avg Value     Std Dev    Curr Value   Min Value   Max Value  No. Changes
----------  ----------  ----------  ----------  ----------  -----------
    0.0932      0.2907      0.0000      0.0000      1.0000         1291

*InputQueue Information*
Queue Number 1 Statistics
Queue Length Statistics
     Time of initialization = 131040.00
     Current Time           = 262080
 Avg Value     Std Dev    Curr Value   Min Value   Max Value  No. Changes
----------  ----------  ----------  ----------  ----------  -----------
    3.9002      2.4988      4.0000      0.0000     24.0000         3873

Time In Queue Statistics
     Time of initialization = 131040.00
     Current Time           = 262080
Total Obs.   Avg Obs.  Std Dev.    Last Obs.   Min Obs.   Max Obs.
----------   --------  --------    ---------   --------   --------
      1935   259.6750  700.5972     247.0486    10.0000 10026.0903

*OutputQueue Information*
Queue Length Statistics
     Time of initialization = 131040.00
     Current Time           = 262080
 Avg Value     Std Dev    Curr Value   Min Value   Max Value  No. Changes
----------  ----------  ----------  ----------  ----------  -----------
    1.6894      2.8703      0.0000      0.0000     15.0000         3873

Time In Queue Statistics
     Time of initialization = 131040.00
     Current Time           = 262080
Total Obs.   Avg Obs.  Std Dev.    Last Obs.   Min Obs.   Max Obs.
----------   --------  --------    ---------   --------   --------
      1937   114.3379  215.8586      30.5694     0.0000  1373.9861

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op1  (a Production Operator)
     -------------------------------------------------------
     Utilization Information
```

Time of initialization = 131040.00
Current Time = 262080

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.2979	0.4573	1.0000	0.0000	1.0000	3381

Break Times Information
Time of initialization = 131040.00
Current Time = 262080

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.2848	0.4513	0.0000	0.0000	1.0000	1245

Setup Times Information
Time of initialization = 131040.00
Current Time = 262080

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
817	17.2950	3.6333	20.0000	10.0000	20.0000

Unloading Times Information
Time of initialization = 131040.00
Current Time = 262080

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
872	28.5436	13.3185	40.0000	10.0000	40.0000

Walking Times Information
Time of initialization = 131040.00
Current Time = 262080

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
1420	0.6359	0.7107	0.0000	0.0000	2.0000

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op2 (a Production Operator)

Utilization Information
Time of initialization = 131040.00
Current Time = 262080

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.2360	0.4246	0.0000	0.0000	1.0000	4311

Break Times Information
Time of initialization = 131040.00
Current Time = 262080

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.2908	0.4541	1.0000	0.0000	1.0000	1271

Setup Times Information
Time of initialization = 131040.00
Current Time = 262080

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
1095	13.2329	3.5071	15.0000	10.0000	20.0000

Unloading Times Information

Time of initialization = 131040.00
Current Time = 262080

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
1041	15.7829	9.6719	15.0000	10.0000	40.0000

Walking Times Information
Time of initialization = 131040.00
Current Time = 262080

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
1902	0.6845	0.6466	1.0000	0.0000	2.0000

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jr1 (a Job Releaser)

Stopped Jobs Information
Time of initialization = 131040.00
Current Time = 262080

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
105	0.0000	0.0000	0.0000	0.0000	0.0000

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mt1 (a Maintenance Technician)

Utilization Information
Time of initialization = 131040.00
Current Time = 262080

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.1394	0.3464	0.0000	0.0000	1.0000	517

Break Times Information
Time of initialization = 131040.00
Current Time = 262080

Avg Value	Std Dev	Curr Value	Min Value	Max Value	No. Changes
0.1467	0.3539	0.0000	0.0000	1.0000	963

Maintenance Times Information
Time of initialization = 131040.00
Current Time = 262080

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
258	70.8140	177.5266	30.0000	30.0000	840.0000

Walking Times Information
Time of initialization = 131040.00
Current Time = 262080

Total Obs.	Avg Obs.	Std Dev.	Last Obs.	Min Obs.	Max Obs.
258	0.1008	0.3016	1.0000	0.0000	1.0000

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Appendix F: Smalltalk Classes and Code for IASE

Due to extensive coding, the implemented Smalltalk code is not included in this paper. The code is available at the IME department at Oregon State University. Dr. Terrence G. Beaumariage maintains the files and print out copies.