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# An analysis of traditional work scheduling rules for a flexible manufacturing system

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AN ANALYSIS OF TRADITIONAL WORK SCHEDULING RULES FOR A FLEXIBLE MANUFACTURING SYSTEM

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# An analysis of traditional work scheduling rules for a flexible manufacturing system

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# I. STATEMENT OF PROBLEM

Flexible Manufacturing Systems (FMS) have been defined as production systems for small batches where manual, semiautomatic, or fully automatic workstations are directly serviced by an automated material handling system and controlled by a computer (1). An FMS operates as an integrated system and is capable of processing a variety different part types simultaneously at various workstations (2).

Diesch (3) modeled a miniature FMS that was a closed-loop system controlled by two microcomputers, a Commodore CBM 8032 and a Radio Shack TRS-80 Model III. It consisted of four major components including the AS/RS (Automatic Storage/Retrieval System), eight storage areas, six machine centers and a turning cell.

By a 'RANDOM' priority dispatching rule, a part was dispatched from one of the storage areas, and deposited in the turning cell or at one of the machine centers. The machine center which had the least amount of total processing time in queue (WINQ) was selected. Under the effects of breakdowns of the AS/RS, the turning cell and the machine center, the system effectivity was analyzed, and ultimately described by a multiple linear regression model.

This research is a significant extension of Diesch's work. Its purpose has been to evaluate traditional job shop scheduling rules using the FMS physical model. There were two major groups of rules. These include part selection rules and machine center selection rules. A part selection rule was defined as a decision rule for selecting a part from one of the identical FMS storage areas. The machine center selection rule was defined as a decision rule for depositing the part in one of the FMS's identical machine centers. Seven priority dispatching rules were used for the part selection, and four machine center selection rules were used for machine center selection. Table 1-1 lists both groups of decision rules.

Table 1-1. Decision rules evaluated (4)(5)(6)(7)

| Part selection rules |
|---|
| RANDOM |
| SPT (shortest processing time) |
| SLACK (least slack time remaining) |
| DDATE (earliest due date) |
| S/PT (smallest slack time per processing time remaining) |
| VALUE (highest dollar value) |
| FSFS (first storage area first served) |
| **Machine center selection rule** |
| RANDOM |
| NINQ (least number of parts in queue) |
| WINQ (least amount of processing time in queue) |
| FMFS (first machine center first served) |

A decision rule set consisted of one dispatching rule and one machine center selection rule. Therefore, the total number of sets that has been evaluated is twenty-eight.

Seven different groups of workparts could be processed by the FMS model. Relevant production information relied on actual industrial data. It consisted of process sequence, processing time, due-dates, and (dollar) value of a workpart. This information was obtained from a midwestern manufacturing facility. The FMS model used in this research simulates the operation of an actual FMS that is currently being installed by this organization.

The performance of a decision rule set in the model was dependent upon random breakdowns of major components during simulation. FMS subsystems were all subject to failures. In this study, the effects of such failures were investigated. Also, rule performance was dependent upon the maximum queue length of the machine center waiting line or the turning cell waiting line. That is, a part was dispatched from the storage area only when a machine center or the turning cell input queue had an available space.

To evaluate the performance of decision rules in the model, the following six performance measures were used.

- System effectivity - The ratio of the actual time to produce parts divided by the available simulation time.
- Part traveling time - The time required to fetch a part from storage and deposit that part in the desired machine queue.
- Actual production output - Actual production quantity during simulation.
- Manufacturing throughput time - The manufacturing time of all processed parts during the available simulation time.
- Work-in-process inventory - The number of parts waiting in the model or total processing time of the parts waiting in the machine centers.
- Production lateness - The difference between the completion time and the due-dates. The completion time was the sum of arrival time, processing time, and waiting time.

Each performance criterion was measured at the end of the simulation. To observe chronological changes of the model's operation under various decision rules, the performance criteria were measured at specific time intervals during each simulation. Also, some statistical relationships between performance criteria were determined and analyzed.

Extensive work has been done to evaluate job shop sequencing rules. Such work has dealt with various job shops. Some work, however, has addressed flexible manufacturing. This literature is reviewed and summarized in Chapter 2.

# II. REVIEW OF RELEVANT LITERATURE

## A. Introduction

Job shop scheduling has been considered an important part of the overall production control problem. An optimal sequence to process jobs at machine centers makes effective utilization of limited manufacturing capacity.

During the past 30 years, many scheduling rules have been introduced. Smith (8), Jackson (9), Little, Mutty, Sweeney, and Karel (10), Bellman (11), Johnson (12), Akers (13) and Bowman (14) were among the earliest. These authors developed basic algorithms which have been used up to now. Their studies focused on the job shop as a queuing system. The rules are those that simply resolve the conflict that arises whenever two or more jobs are waiting for the services of a single machine and a decision must be made as to which to process first. Efforts are continuing to find optimal sequences as functions of the diversity of jobs, the variability of machines and the size of system. A detailed description of the work done in this area up to 1961 can be found in articles written by R. L. Sisson (15,16).

There have been many investigations in which a digital computer has been used to generate schedules for a variety of different n/m problems where n is the number of jobs and m is the number of machines in the shop. Jackson and Nelson (17), Jackson (18), and others did early work which has been focused on various comparative studies of priority dispatching rules through the use of computer simulation.

## B. Summary of Dispatching Rules for Job Shops

For convenience of review, the priority dispatching rules which have been used as background for this research are summarized in Table 2-1 (4, 5, 6, 7, 19, 20, 21).

Rules 1 to 22 and Rules 32 to 34 might be considered to be basic rules. Rules 23 to 28 are essentially combinations of various basic rules. Rules 29 to 31 and Rules 35 to 36 are modified SPT rules by which an individual job is limited the length of waiting time. Rules 37 to 41 are rules developed by considering setup time.

## C. General Assumptions for Past Investigations

Different investigators have simulated different dispatching rules with different assumptions for the basic job shop problem. The general assumptions used by the investigators are as follows (22):

- The job processing times, including the setup time, are known and are sequence independent;
- Transportation times between facilities are neglected;
- Once a job is started on a facility, it is processed to completion (no preemption);
- The shop has a fixed, known, labor and machine capacity;
- Machines do not break down;
- There are no merging or assembly operations (Each job represents a job order having a single item for processing);
- Jobs do not recycle due to fabrication errors, engineering changes, etc.;
- Only one job may be processed on one machine at a given time;

Table 2-1. Summary of dispatching rules

| NO. | Rules | Descriptions |
|---|---|---|
| 1 | RANDOM | Job is selected which has the smallest value of a random priority assigned at time of arrival at queue (note that a job receives a new number for each of its operations). |
| 2 | FCFS | Job is selected which arrived at the queue first. |
| 3 | LCFS | Job is selected which arrived at the queue last. |
| 4 | FASFS | Job is selected which arrived at the shop first. |
| 5 | SPT | Job is selected which has the shortest operation processing time. |
| 6 | LPT | Job is selected which has the longest operation processing time. |
| 7 | FOPNR | Job is selected which has the fewest operations remaining to be performed. |
| 8 | MOPNR | Job is selected which has the most operations remaining to be performed. |
| 9 | LWKR | Job is selected which has the least work remaining to be performed. |
| 10 | MWKR | Job is selected which has the most work remaining to be performed. |
| 11 | TWORK | Job is selected which has the greatest total work (all operations on the routing). |
| 12 | NINQ | Job is selected which will go on for its next operation to the shortest queue. |
| 13 | WINQ | Job is selected which will go on for its next operation to the queue with the least work. |

Table 2-1. (continued)

| NO. | Rules | Descriptions |
|---|---|---|
| 14 | XWINQ | Job is selected which will go on for its next operation to the queue with the least work. The queue is considered to include jobs now on other machines that will arrive before the subject job. |
| 15 | DDATE | Job is selected which has the earliest due-date. |
| 16 | SLACK | Job is selected which has the least slack time determined by due-date minus all remaining processing time for the job. |
| 17 | OPNDD | Job is selected which has the earliest operation due-date. Equally spaced due dates are assigned to each operation at the time job enters shop. |
| 18 | S/OPN | Job is selected which has the least ratio of slack time divided by the remaining number of operations. |
| 19 | S/PT | Job is selected which has the least ratio of slack time divided by remaining processing time. |
| 20 | DS | Job is selected which has the least slack time determined by due-date less the remaining expected flow time minus the current date (dynamic slack). |
| 21 | DS/PT | Job is selected which has the least ratio of dynamic slack time divided by the remaining processing time. |
| 22 | DS/OPN | Job is selected which has the least ratio of dynamic slack time divided by the remaining number of operations. |
| 23 | P+WKR(a) | Job is selected which has the smallest weighted sum of next processing time and work remaining. 'a' is a weighting constant which is greater than 0. |

Table 2-1. (continued)

| NO. | Rules | Descriptions |
|---|---|---|
| 24 | P/WKR(a) | Job is selected which has the smallest weighted ratio of next processing time to work remaining. 'a' is a weighting constant which is greater than 0. |
| 25 | P/TWK | Job is selected which has the smallest ratio of next processing time to total work. |
| 26 | P+WQ(a) | Job is selected which has the smallest weighted sum of next processing time and work in the following queue. 'a' is a weighting constant which is greater than 0. |
| 27 | P+XWQ(a) | Job is selected which has the smallest weighted sum of next processing time and work (including expected work) in the following queue. 'a' is a weighting constant which is greater than 0. |
| 28 | P+S/OPN(a,b) | Job is selected which has the smallest weighted sum of next processing time and slack time per operation remaining. Both 'a' and 'b' are weighting constants. Both are greater than or equal to 0. Each particular set of the parameters(a,b) represents a different priority rule. |
| 29 | SPT-T(a) | This is a truncated version of SPT. As long as no job in the queue from which selection is made has waited more than 'a' time units in this queue, normal SPT selection is made. When a job has waited too long, it is given dominating priority. |
| 30 | FCFS(a) | This is a variation of FCFS in which SPT selection is invoked for a particular queue whenever that queue becomes too long. If there are fewer than 'a' jobs in queue at the time of selection, the earliest arrival (to the queue) is chosen. If 'a' or more jobs exists, then the job with the shortest processing time is chosen. |

Table 2-1. (continued)

| NO. | Rules | Descriptions |
|---|---|---|
| 31 | SPT-2C(a) | This is a two-class variation of SPT. A fraction of the jobs, denoted by 'a', are identified as preferred. Job is selected which has the shortest processing time among the preferred class of jobs; if no preferred jobs are in queue, then the shortest processing time among other jobs applies. |
| 32 | FCFS(pr) | Priority depends on the (dollar) value of the job. Jobs are divided into two classes- a high value class and a low value class. All high value jobs are assigned greater priorities than all low value jobs. Within the class, the priority is assigned in arrival order (FCFS). There is actually a family of rules of this type which can be parameterized by 'pr', the proportion of jobs assigned to the low value class. |
| 33 | VALUE | Priority is directly related to the (dollar) value of the job. The priority is taken to be equal to the value of the job. |
| 34 | NINQ(q) | Priority is related to the subsequent move. Maximum priority is given to that job which on leaving this machine will go on to the next machine which has the shortest (in the sense of least processing time) critical queue. If no queue is critical, the selection is in arrival order (FCFS). A queue is considered critical when it has less than a specified number of time units of processing time waiting. There is actually a family of rules of this type which can be parameterized by 'q', the value below which a queue becomes critical. |
| 35 | Est.-SPT(a) | Job is selected which has the smallest estimated processing time (% errors of estimate assumed uniformly distributed between $\pm$ a). |

Table 2-1. (continued)

| NO. | Rules | Descriptions |
|---|---|---|
| 36 | 2-Class(a) | Job is selected which arrived first among the "short" jobs; if no "short" jobs are in queue, then the "long" job which arrived first (probability that job is correctly classified short or long is 'a'). |
| 37 | FIXSEQ | Job is selected first which is contained in a given class. After processing all jobs in the class, another class is processed in a fixed class sequence. |
| 38 | MINSEQ | Job is selected which has the minimum setup time. |
| 39 | FIXSEQ-S | Job is selected which has the shortest service time after choosing a particular class of jobs in the fixed sequence. |
| 40 | MINSEQ-S | Job is selected which has the shortest service time after choosing a particular class for which the setup time is minimum. |
| 41 | SSS | Job is selected which has the minimum sum of setup time and service time. |

- Only one machine type is required for any given operation;
- There is no alternative process routing;
- Lot splitting and phase lapping are not permitted;
- Data is collected after the shop is operating under stable conditions.

### D. Detailed Review of Relevant Investigations

#### 1. Review of preliminary work

In 1957, Jackson (18) developed a priority index to obtain decision rules for job assignments with minimum tardiness. The priority index (P(ab)) was defined as;

P(ab)= (due-date) - (time required for future moves) -
a * (expected time required for future machining)
+ b * (expected time for present machining
operation)

The job for which the value of P(ab) is smallest is processed first. P(ab) values were calculated for all combinations of a= 1, 2, 3 and b= 0, 1; and also for a= 0, b= 0.

The job shop considered had eight machines used to process seventy jobs. The number of machining operations, the actual sequence of machines, the average values for the processing time distributions and the due-dates were determined by a random process. A job's tardiness was the main performance criteria to find the (a,b) combinations yielding the best decision rule. The best output was obtained when both a= 1 and b= 1.

Baker and Dzielinski (23) showed the results of some digital computer simulation studies of a simplified model of a job shop production process. Such factors as the average effectiveness of schedules under the impact of random variations in processing times and the effect of changing dispatching rules were considered. The average manufacturing times and predictability of completion times were used as measures of effectiveness.

The process routing and the processing time for each job were generated with the aid of pseudo-random number processes and routine statistical procedures. Two parameters were controlled: the shop size in terms of the number of facilities and the average number of processing operations on each job.

The expected amount of processing on each facility was the same. The extent of the variations in the expected processing time ranged from 0 to 0.5. These variations were introduced to reflect the differences in work rates that occurred in real production processes and were represented by a negative exponential distribution. Two successive processing operations were not permitted at the same facility (machine). The average number of processing operations per job per load ranged from 2 to 10. The shop size ranged from 9 to 30 machines.

Through an analysis of variance, it was shown that the shop size had no significant effect on the job's total manufacturing times at the 5% level. The authors found that there is a linear response of the number of processing operations per job per load and the variation in the expected processing times. They measured the effect of changing a shop's operating policy. They determined the effect of priority dispatching rules upon the average of the job's total manufacturing times and also upon the predictability of the job's completion times.

The following rules were tested.

- . SPT (Rule 5)
- . LPT (Rule 6)
- . FOPNR (Rule 7)
- . MOPNR (Rule 8)
- . LWKR (Rule 9)
- . MWKR (Rule 10)

These rules were applied to both those jobs belonging to the oldest uncompleted load in the shop and all jobs in the shop. The SPT rule was found to yield the minimum average manufacturing time for both conditions.

The authors found a linearly increasing relationship between the job's total expected processing time and the number of its processing operations with the SPT rule using a statistical analysis. With the linearly increasing function, they predicted the expected completion time of new jobs and established an error sensing control equation.

2. Review of an experimental investigation

Conway, Johnson and Maxwell (4) evaluated 13 dispatching rules using the Cornell Research Simulator (24), a program which simulates the operation of a network of queues on a basic punch card IBM 650 computer. Thirteen dispatching rules were evaluated;

| | | | |
|---|---|---|---|
| . RANDOM | (Rule 1) | . MWKR | (Rule 10) |
| . FCFS | (Rule 2) | . DDATE | (Rule 15) |
| . SPT | (Rule 5) | . SLACK | (Rule 16) |
| . LPT | (Rule 6) | . FCFS(pr) | (Rule 32) |
| . FOPNR | (Rule 7) | . VALUE | (Rule 33) |
| . MOPNR | (Rule 8) | . NINQ(q) | (Rule 34) |
| . LWKR | (Rule 9) | | |

In Rule 32, six different proportions (pr) of jobs were assigned to the low-value class; pr=0, 0.2, 0.3, 0.4, 0.6 and 1. In Rule 34, three different values were considered to determine the maximum queue length by which a queue becomes critical; q=5, 10 and 99. The test was performed upon a shop that consisted of five machines, all different. The expected number of operations on each machine was equal (4 operations per job). The operation time distributions were generated from a Poisson distribution.

The jobs were assigned a (dollar) value from a Log Normal distribution and were assigned a total allowable processing time (due-date minus release time) from a Normal distribution. To investigate the effects of the level of load upon the shop, the authors used three different levels designed as heavy, medium, and light on the basis of approximate average total processing time. Performance measurements were job completion time, lateness, the dollar-days of queue time (work-in-process) and facility utilization. A hundred jobs were simulated to collect performance statistics of each dispatching rule.

As results, Rules SPT (Rule 5), MOPNR (Rule 8) and VALUE (Rule 33) performed very well in mean lateness and machine utilization no matter which load was applied. These rules, however, had high values of standard deviation in comparison with other remaining rules. With the criteria of average dollar-days of queue inventory, the VALUE (Rule 33) performed better than the FCFS(pr) (Rule 32). That is, it was shown that a rule with a single class with different (dollar) values performed better than a rule with multiple classes of (dollar) values.

The authors concluded that a 'good' rule will have the following characteristics;

- It will approach a max-min pairing of completion time and value of the job;
- It will have a low mean completion time;
- It will have a large variance of completion times.

## 3. Review of an investigation oriented to work-in-process inventory

Conway (5) investigated 17 priority dispatching rules by means of IBM 7090 and SIMSCRIPT as a program language. The shop consisted of nine machine groups. All of processing times were considered to be random variables and were obtained using an exponential distribution. The mean of those processing times was equal to 1. A sequence of ten thousand jobs was stored on a magnetic tape. The number of operations per job was a random variable whose expected value was equal to the number of machine groups. The model studied extracted the essence of the job shop process - it was essentially a network of queues.

Seventeen dispatching rules were evaluated. They were:

- RANDOM (Rule 1)
- FCFS (Rule 2)
- FASFS (Rule 4)
- SPT (Rule 5)
- LPT (Rule 6)
- FOPNR (Rule 7)
- LWKR (Rule 9)
- MWKR (Rule 10)
- TWORK (Rule 11)
- NINQ (Rule 12)
- WINQ (Rule 13)
- XWINQ (Rule 14)
- P+WKR(a) (Rule 23)
- P/WKR(a) (Rule 24)
- P/TWK (Rule 25)
- P+WQ(a) (Rule 26)
- P+XWQ(a) (Rule 27)

In Rule 23, the values of 'a' were 0.91, 0.976 and 0.985. Rule 24 had the values of 'a' equal to 0.05, 0.25, 0.5, 0.75, 1.0, 1.2 and 2.0. For Rule 26, the values of 'a' were 0.5, 0.9, 0.95 and 0.97. Rule 27 had the values of 'a' equal to 0.944, 0.96 and 0.98. The assumptions adopted for the study were the same as the general assumptions of Section B of this chapter.

The major performance criterion was work-in-process inventory (WIP). It was measured in four different ways:

- Work Remaining - the sum of the processing times of all operations not yet complete or in process for all jobs in the shop;
- Total Work Content - the sum of the processing times of all operations of all jobs in the shop;
- Work Completed - the sum of the processing times of all completed operations of all jobs in the shop;
- Imminent Operation Work Content - the sum of the processing times of the particular operations for which jobs were waiting in queue.

In addition, Conway also considered the aggregate number of jobs in the system. The mean value for each method was computed for each interval of 400 time units, representing on the average, the arrival of 360 jobs. A sequence of twenty-six such interval means was obtained for each method, representing a total run of 10,000 jobs.

The smallest value of mean number of jobs in queue was observed for Rule 27, P+XWQ(0.96). Both the total work content and the work completed were minimized by Rule 25, P/TWK. The mean work remaning was a minimum on Rule 24, P/WKR(1.0). Although the SPT rule did not exhibit the minimum value for any of the measures of performance, it nevertheless dominated the set of rules tested. It was an important component of every one of the rules that did exhibit optimal values of performance.

Conway developed three modified SPT rules to limit the length of time that an individual job might wait. Those rules were SPT-T(a) (Rule 29), FCFS(a) (Rule 30) and SPT-2C(a) (Rule 31). When the value of 'a' was equal to infinity (as the in SPT-T(a) rule), or the value of 'a' was equal to 1 (as in both FCFS(a) and SPT-2C(a)), these rules became the same as the SPT rule. These modified rules performed the best with the performance criterion of mean number of jobs in queue. This suggested that the SPT rule was very sensitive to truncation. In his study, Conway recommended the SPT rule which was earlier and simpler to implement. This rule was recommended because of its excellent performance under every performance measure.

4. Review of an investigation oriented to job lateness

Conway (6) continued his previous study (5) with different dispatching rules and different performance measurements. He investigated ten dispatching rules with job lateness as the main performance criterion. Both the assumptions used and the shop size were the same as his previous study. He used four different methods to determine the job due-date from which job lateness is obtained. The lateness of a job was simply the difference between the actual time at which it was completed and the time at which completion was desired. The time at which completion was desired was called as the job due-date. The four different methods used to determine the job due-date were:

- For TWK due-dates, the allowable shop time (that is, the difference between the due date and the time the job arrives in the shop) was made proportional to the sum of the processing times of the operations of a job. The proportion constant was 9;
- For NOP due-dates, the allowable shop time was made proportional to the number of operations of a job. The proportion constant was 8.883;

. For CON due-dates, the allowable shop time was a constant amount, independent of any characteristic of the job to which it is assigned. The constant amount was 78.7985;

. For RDM due-dates, the allowable shop time was assigned at random. Allowance were uniformly distributed between 0 and 157.597 time units;

For each method, a variety of dispatching rules were tested. The rules tested were:

| | | | |
|---|---|---|---|
| . RANDOM | (Rule 1) | . DDATE | (Rule 15) |
| . FCFS | (Rule 2) | . SLACK | (Rule 16) |
| . FASFS | (Rule 4) | . OPNDD | (Rule 17) |
| . SPT | (Rule 5) | . S/OPN | (Rule 18) |
| . LPT | (Rule 6) | . P+S/OPN(a,b) | (Rule 28) |

For Rule 28, P+S/OPN(a,b), the values of 'a' were 0, 0.3, 0.5 and 0.75, and the values of 'b' were 0.5, 0.8, 1.0 and 1.2.

Overall, Conway showed that the SPT rule exhibited the best performance of all the rules tested. It had the minimum lateness for all the methods by which job due-date was determined. The rule had the maximum positive lateness for RDM method. It should be noted that the SPT rule does not consider the due date in its operation. It is less sensitive to the method of assigning due-dates than the other rules. Of those rules that used the due-date, S/OPN (Rule 18) was the best performer for both the TWK due-dates and the NOP due-dates. The rules, DDATE and OPNDD performed very well for the TWK due-dates. Both of Conway's studies are well-summarized in reference (7).

5. Review of investigations considering setup time

Baker (19) considered dispatching rules with sequence-dependent setups in a single channel system. The setup time was dependent upon both the class of the job leaving the facility and the class of the job entering the facility. All assumptions except the existence of setup time were the same as the general assumptions described in the preceding section.

Jobs arrived at the queue in a Poisson process (mean arrival rate= 0.6), with exponentially distributed service times (mean service rate= 0.8). Jobs were classified into one of five setup classes. A specific setup time was given to each class of jobs.

The dispatching rules tested were:

- FCFS (Rule 2)
- SPT (Rule 5)
- FIXSEQ (Rule 37)
- MINSEQ (Rule 38)
- FIXSEQ-S (Rule 39)
- MINSEQ-S (Rule 40)
- SSS (Rule 41)

Two performance criteria were used; mean flow time and number of idle periods. A greater number of idle periods indicated a lower utilization. Performance statistics were collected for 3,000 completed jobs.

Baker found that the SPT rule minimized expected flow time. The FCFS rule had minimum value of idle periods. Under extremely heavy congestion, or in cases where the ratio of setup time to service time was high, FIXSEQ was found to operate as well as or better than SPT.

Moodie and Roberts (25) simulated priority dispatching rules in a parallel processor shop utilizing GPSS-III language on an IBM 7094 computer. A parallel processor shop was one where all the processing facilities were identical and any input to the shop may be processed on any facility. The authors used an actual shop producing phonograph records. The shop included 24 presses. Two setup workers were assigned to this equipment for loading/ unloading. The pressing operation took 32 seconds per record, and approximately 15 minutes were required to tear down and set-up a press.

In order to see how the dispatching rules would perform under different shop loads, the number of arrivals was incremented by one with the specified distribution. That is, the mean arrival rate for the first distribution was 10, the second distribution was 11, and that for the third was 12. The priority dispatching rules investigated were:

- FCFS (Rule 2)
- DDATE (Rule 15)
- SPT (Rule 5)
- SLACK (Rule 16)

As another rule, the authors introduced a 'weighted objective' method. A rule which performed exceptionally well in one shop may fail to perform as well in another shop due to the uniqueness of various facilities. Hence, the philosophy of the weighted objective method was to combine other established rules in such a way as to reflect overall optimality with respect to a set of criteria for the specific shop under consideration.

Mathmatically, the weighted objective rule was stated as follows:

$$D(j,k) = \sum_{i=1}^{n} W(i) * R(i,j,k) \qquad (2\text{-}3)$$

subject to

W(i) = 1
R(i,j,k) <= 1

where

D(j,k) = priority index of a job j on machine k;
R(i,j,k) = ratio of the best value for rule i divided by rule i value for job j on machine k;
W(i) = weighting of the i th rule;
i = an index for a rule;
j = an index for a job;
k = an index for a machine;
n = number of rules combined.

For each rule, the shop was simulated on a 480 minutes for 365 days. Performance criteria consisted of flow time, lateness and tardiness (positive lateness). To determine lateness, the due dates were assigned by augmenting the processing time by 20 percent and adding to the result a uniformly distributed random variate between 0 and 99.

Every job arrival was required to wait for a machine to become available in the shop (Queue 1). Once the machine became available, the job entered Queue 2 to wait for a setup worker. The available machine was referred to as Storage 1, and the available setup worker was referred to as Storage 2. Statistics were gathered for Queue 1, Queue 2, Storage 1, and Storage 2.

The simulation results showed that the SPT rule almost always gave the minimum flow time. The SPT, DDATE, and weighted objective rules minimized mean lateness. The SPT and SLACK rules were used for investigation of the effects of varying weights. SLACK and weighted objective rules minimized overall tardiness. In general, the use of rules such as SPT, SLACK and weighted objective showed substantial improvement over using no rule at all (FCFS) in the parallel processor shop.

## 6. Review of investigations considering dynamic dispatching rules

Buffa and Miller (20) illustrated two methods for classifying priority dispatching rules for machine limited systems. The first was on the basis of information availability. A local rule determined priorities entirely on the basis of the information available at the time of dispatch (for example, its processing time or due dates). More global rules might take into account overall job load, the status of the load on workcenters downstream, or changes in due-dates.

The second basis of classification was static versus dynamic rules. In static rules, relative priorities remained the same once assigned. With dynamic priority rules, the relative priority position changed over time.

The authors reviewed the Nanot study (21) for detailed investigations that utilized these classification schemes. The Nanot study involved six different job shop structures and tested ten different priority dispatching rules. Each structure had information for applying global rules. Both static rules and dynamic rules were investigated. The ten dispatching rules used were:

| | | | |
|---|---|---|---|
| . FCFS | (Rule 2) | . S/OPN | (Rule 18) |
| . LCFS | (Rule 3) | . S/PT | (Rule 19) |
| . FASFS | (Rule 4) | . DS | (Rule 20) |

. SPT (Rule 5) . DS/PT (Rule 21)

. SLACK (Rule 16) . DS/OPN (Rule 22)

The arrival of orders in the system followed a Poisson process, and the service times were drawn from a negative exponential distribution. Other assumptions were basically same as the general assumptions of Section B in this chapter. Due dates were assigned to jobs by adding an 'urgency number', drawn from a fixed distribution, to the expected flow time calculated for a job under FCFS discipline (26). The SPT rule consistently had the lowest mean flow time. The standard deviations of the FCFS and FASFS rules were in general low. The S/PT rule was consistently the worst performer.

Nanot investigated the influence of system configuration through the mechanism of an analysis of variance. The results showed that the difference due to the use of different priority dispatching rules was highly significant, Nanot found that the difference due to system configuration was much less significant. This conclusion was the same as that reached by Baker and Dzielinski (23).

7. Review of an investigation considering production capacity

Buzacott (27) studied the way in which to determine the production capacity or maximum departure rate of jobs from a job shop with limited storage space. For a job shop with two identical machines and random routing of jobs, a number of release rules were compared. Input to the shop was Poisson, and the processing time was exponential. The dispatching rule used for the shop queue was independent of a job's processing times and number of operations. The shop input queue was the queue of jobs in front of the shop when all the spaces in a specified machine queues were full. Before a job was released to the shop from the shop input queue, it was necessary to ensure that there was a space available in the queue at the machine for its first operation.

Buzacott defined five dispatching rules which were different from the common dispatching rules due to the limited queue length. They are summarized below:

- Rule 1. Release jobs to the shop as soon as space becomes available - As soon as a job left the shop and thus created a space in one of the machine queues, the appropriate job was released from the shop input queue to the machine queue.
- Rule 2. Restricting selection from the shop queue - This rule was to restrict the selection from the shop input queue to the first n jobs in it. If none of the jobs were for the machine with the empty queue space, then the space would be left unoccupied.
- Rule 3. Limiting the total number of jobs in the shop (Random Selection) - This rule was to set an upper limit on the total number of jobs allowed in the shop. It was assumed that the selection from the shop input queue was made at random.
- Rule 4. Optimum selection with number of jobs in shop constant (Balanced Queue rule) - The optimum rule was to select from the shop input queue a job with its first operation on the machine with the shortest queue. In order to find the optimum rule, a dynamic programming approach for the Markov process was used.

In order to measure the effect of limiting the length of the machine queue, Buzacott computed the shop capacity. The shop capacity for each rule was determined by the probability transition matrix generating the routing of jobs. By solving the state transition equation in the steady state, he obtained a shop capacity for each rule.

His conclusion was that if there was limited storage space at machines in a job shop, then there was an optimum upper limit to the number of jobs which should be allowed in the shop. This limit was found to be less than the total storage space at machines. Finally, two rules, the balance queue rule (Rule 4),and the idle machine rule (Rule 5) were found to be optimum.

## E. FMS Design and Analysis Efforts

### 1. FMS design issues

Hutchinson and Wynne (28) addressed two tasks associated with flexible manufacturing systems. The first was determining what type of physical configuration would serve most effectively in production of factory output (system effectiveness). The second was determining what type of control logic, or set of interacting decision rules, would operate a specific FMS configuration most efficiently (system efficiency). The former was FMS design issue, and the latter was FMS decision issue.

A discrete event simulation (SIMSCRIPT) was used to gain an understanding of the hypothetical FMS result sensitivity to the many probable combinations of configuration design and decision rule options. A specific FMS was used for the simulation. The system had ten DNC machines served by both ten on-shuttles and ten off-shuttles, three carts, nine manual workstations, and four I/O stations.

Thirty-two simulations were performed based upon all combinations of five different independent variables. The five different variables were:

- The number of pallets;
- Speed of carts;
- The number of positions of on-shuttles;
- The number of positions of off-shuttles;
- Workload of jobs.

Eleven performance measures were used. They were:

- The number of complete uses of a fixture achieved on a part;
- The number of parts completed by each of the DNC machines;
- The aggregate production hours;
- The average idle time of a work station;
- The average delivery time to a work station;
- The average idle time of a part on a work station;
- The average idle time of DNC machines;
- The fraction of time during which cart is congested;
- The number of material handling system (MHS) stations traversed by carts;
- The proportion of the actual running time of a cart;
- The fraction of the idle time of a cart.

FMS production was measured by three of these dependent variables: the number of complete uses of a fixture, the number of parts completed, and the aggregate production hours.

The authors concluded that more on-shuttles, faster carts and a supply of extra pallets had the most favorable impact upon increasing effective FMS production. This reduced unused DNC capacity and simplified the MHS operating rules. The authors also found that when relatively few parts were on off-shuttles or carts, the FMS system would operate best. To achieve this goal, the thirteen MHS decision rules were found to be advantageous. They were:

- Allow the empty carts to circulate unassigned within each of the DNC station;

- When an empty cart becomes blocked at a station, move the cart to the adjacent station;

- The movement of a pallet onto an off-shuttle should initiate a call for the next upstream empty cart;
- The movement of a part onto an off-shuttle which already contains a waiting pallet should result in a priority call for the next upstream empty cart;
- Any cart carrying a part which could provide work for an idle machine which is the part's next preferred machine should receive a top priority call;
- If no part is within the FMS whose next preferred operation is on the idle machine, any cart carrying a part which can utilize that idle DNC next should be given a call;
- If the parts-set stock for one FMS dependent assembly line falls below a buffer level, those parts in short supply should create a low priority call for their carts;
- When two carts are contesting to advance, the one with the higher priority should take precedence;
- When two carts of equal priority are contesting to advance, the one carrying the part with lowest hours ahead of standard status should take precedence;
- In no case should a loaded pallet utilize a DNC work station as a mere travel path;
- Enter parts into an FMS, which feeds even one assembly line, on the basis of assembly bill-of-material;
- Enter parts into an FMS on the basis of lowest hours ahead of standard per part;
- Carts carrying completed parts to one of the FMS output stations should defer to all other non-empty and priority possessing carts after they have cleared the off-shuttle transfer station.

2. FMS analysis efforts

Diesch (3) developed a physical model of an FMS. This model was a miniature version of an actual metal working facility by which seven different types of workparts were manufactured.

The system components (3, 29) were as follows:

- Seven storage areas - all identical. Each area was classified by a specific workpart type;
- One semi-finished storage area - this area was for workparts to be processed in a subsequent operation;
- An Automatic Storage/Retrieval System (AS/RS) - the system contained an AS/RS cart, two lifting ramps and two overhead conveyors. The work parts were selected from the storage area and transported to the machine centers using this system;
- Six machine center cells - all identical. Each machine center cell contained both one machine and a waiting line storage area;
- One turning cell - the cell contained two vertical lathes which were loaded/unloaded by an industrial robot, a washing machine, a waiting storage area, and a finished product storage area;
- Two microcomputers - One Radio Shack TRS-80 Model III for control of the industrial robot. A Commodore CBM 8032 controlled the rest of the FMS;

The system contained two parallel structures: one was for the storage areas, and another structure correspondad to the machine center cells.

Diesch spent most of his efforts in constructing the physical model using Fischertechnik components (30) and common electrical parts. He illustrated both the design and construction method of each of major system components.

The AS/RS was constructed on a horizontal plane. Construction of the cart and track was accomplished by attaching notched track to small Fischertechnik building blocks for support. Next, a small motor and gear was attached to the track. A box was secured to the top of the cart to hold the parts. In order to supply power to the cart's motor, Diesch used 24 gauge copper wire along each side of the cart for the full length of the track. The next effort on the AS/RS cell was the placement of the electric eyes and lights that provided cart location information to the computer. Finally, eight motorized gates were attached to all storage areas for loading parts onto AS/RS cart.

Material handling was accomplished with the use of lifting ramps and gravity feed conveyors.

The turning cell consisted of two large motors with lights to simulate the lathes' operations. These two motors were attached to the base with building blocks. The wash tank was also attached to the base in a similar manner.

The machine centers were constructed in the same manner as the lathes. Motorized gates were attached to track at the machine center diversion points. These gates provided a mechanism to stop the parts while machining was in progress.

Two microprocessors were used for system control. The first was a Radio Shack TRS-80 Model III (16K) for controlling the robot in the turning cell. The second was a Commodore CBM Model 8032 (32K) for controlling the model's motors, monitoring the model's activity, and computing the model's simulation statistics.

The model required 29 output lines and 18 input lines. It was necessary that the I/O lines be separately addressable. The Parallel User Port of the CBM was capable of only seven output lines and one input line. A multiplexer was designed and constructed to expand the seven output lines and one input line of the CBM to 32 output lines and 32 input lines that were separately addressable by the CBM.

Both electric eyes and press switches were used as the model's input circuits. The electric eyes were used to determine the location of the AS/RS cart and to recognize the presence of a part at the turning cell completion queue. Press switchos operated and transmitted various signals to the control computer. The output circuits were of three types: the AS/RS cart circuit, diverter gate circuits, and blocking gate circuits.

Diesch analysed the physical model using physical simulation. Fixed parameters of the model's operation were the processing sequence, the part selection, the machine center selection algorithm and the maximum queue lengths. In the processing sequence, seven different parts could be produced with different routings. The part selection was random. Parts, however, that had completed the turning cell operations (semi-finished parts) were the first to be selected. The machine centers in the model represented identical machine. The machine center selection algorithm was based on the total processing time in each machine center waiting line. A selected part was routed to the machine center with the least amount of total processing time in queue. Maximum queue length at the storage areas, the machine center waiting lines and at the turning cell waiting line were limited to five parts including the part currently being processed.

The principal performance measurement was the system effectivity of the developed FMS. The system effectivity was defined by

$$EFFS = \frac{\left( \sum_{i=1}^{m} RT(i) \right) + RTT}{CAP} \qquad (2\text{-}3)$$

where

EFFs = system effectivity;
RT(i) = cumulative run time for machine center i;
RTT = cumulative run time for the turning cell;
CAP = total machine time available at full production (system capacity);
m = total number of machine centers;
i = an index for a machine center (i=1, 2, ---, 6).

EFFs was computed by the CBM software at the end of each simulation using Equation 2-3. The system capacity (CAP) was the simulation run time (SR) multiplied by seven (six machine centers and the turning cell).

The system effectivity was related to the downtime of the machines and components in the FMS. These downtimes were represented by interference factors I1, I2 and I3. I1 was the machine center interference, I2 was the turning cell interference, and I3 was the material handling system interference. All values ranged between 0 and 1. These values were given as the input data. They were varied as shown below.

| # of Machine centers running | Turning cell interference | Material handling system interference |
|---|---|---|
| 6 for I1 = 0.0 | I2 = 0.0 | I3 = 0.0 |
| 5 for I1 = 0.167 | = 0.10 | = 0.10 |
| 4 for I1 = 0.333 | = 0.20 | = 0.20 |
| | = 0.30 | = 0.30 |

Among these values, I3 was the most important factor in determining the processing times for both the machine center and the turning cell. If the value of I3 was zero, the material handling system was capable of supplying a sufficient quantity of parts to the system to allow production at full capacity. Therefore, if I3 was increased, the processing time of a part was also increased. The system effectivity, therefore, was reduced. Since the speed of the AS/RS cart was constant, the average time required to fetch a part from the storage area and deposit that part at the desired machine waiting line was also constant.

Diesch determined the processing times for the machine centers and the turning cell for all three interference factors. The average fetch time was constant at three minutes per part. To achieve a 'balanced' system, the actual machining times were factored so that the machines in the model would require an average of one part every three minutes. 'Balanced' conditions represent zero values for I1, I2 and I3. Table 2-2 presents the process cycle times used to achieve 'balanced' conditions. Parts 1, 3 and 4 were scheduled for both turning cell and machine center operations. Parts 2, 5, 6 and 7 were scheduled only for a machine center operation. The total processing time to complete the manufacturing operations was 209.9 minutes. This value was the sum of the times for parts 1-7 plus 3 times the turning cell time (for separate processing of parts 1, 3 and 4).

The 209.9 minute total was the number of machine-minutes required to produce the seven parts. The material handling system could supply an average of 10 parts in 30 minutes (the average fetch time was constant at three minutes per part). Since the six machine centers and the turning cell operated simultaneously, seven parts could be manufactured every 209.9/7=30 minutes. Those 'balanced'

Table 2-2. Balanced system process cycle time

| Process for | Cycle time (min.) |
|---|---|
| part 1 | 23.9 |
| part 2 | 41.4 |
| part 3 | 11.5 |
| part 4 | 5.6 |
| part 5 | 7.2 |
| part 6 | 80.2 |
| part 7 | 10.1 |
| turning cell | 10.0 |
| Total | 209.9 |

process cycle time were reduced by a factor of (1 - I3) if the material handling system was unable to supply a sufficient quantity of parts to keep the machines running. For the machine center and the turning cell, the following equations were used.

$$PT = \frac{(10 \text{ minutes}) * (1 - I3)}{(1 - I2)} \qquad (2\text{-}4)$$

$$PT = (10 \text{ minutes}) * (1 - I3) \qquad (2\text{-}5)$$

$$PT = (PT \text{ balanced}) * (1 - I3) \qquad (2\text{-}6)$$

where

PT = the turning cell processing time;
PT = the machine center processing time for a part i;
I2 = the interference factor for the turning cell;
I3 = the interference factor for the AS/RS.

Equation 2-4 was used to determine the turning cell process time for the TRS-80 microcomputer. Equation 2-5 determined the turning cell process time for the CBM 8032 microcomputer.

By varying both the processing times and the value of each of the three interference factors, Diesch obtained a statistical relationship between the system effectivity and the interference factors through 48 hours of physical simulation. According to the statistical relationship, the effects of breakdowns of components to the system effectivity could be predicted. The relationship shown below was obtained by a multiple linear regression program when the system was stabilized.

$$EFFs = (0.91)-(0.7 * I1)-(0.16 * I2)-(0.53 * I3) - (0.66 * I1 * I3)+(1.27 * I2 * I3) \quad (2\text{-}8)$$

### F. Summary

In the review of the dispatching rules, different authors have evaluated different priority dispatching rules for the general job shop under various shop sizes, structures and performance criteria. The analysis tool used has been computer simulation. General assumptions were almost same in each investigation. In most cases, the SPT rule which has a minimum mean flow time was consistently one of the best performers.

Most dispatching rules have traditionally been used for the general job shop which has one single input channel. Machines by which selected jobs were processed have been assumed to be predetermined. A job shop has been usually assumed in which there are no breakdowns and no travelling time between workstations. The FMS model developed by Diesch (3), however, had both seven identical storage areas (a multiple input channel), six identical machine centers and one turning cell. A part was selected from one of storage area with a constant fetch time. There were seven different fetch time values. Parts were provided to one of machine centers with a constant route time. There were seven different route time values. Traveling time of a part was determined by the sum of fetch time and route time.

Diesch studied the effects of breakdowns on system effectivity. The breakdown of the AS/RS was a critical factor in determining processing cycle time of a part. This is because the cycle time was increased if the AS/RS could not supply a sufficient quantity to the machine centers or the turning cell. If the cycle time was increased, then the system effectivity was reduced.

Diesch's model has been used, after significant physical modification, in this study. The purpose has been to determine the best decision rules by which both part selection and machine center selection will be achieved. Six performance criteria were used under the effects of unplanned breakdowns during simulation time as described in Chapter 1.

The following chapter explicitly describes the modified physical model and its revised physical mode of operation. Model components which failed randomly are described in detail as well.

# III. THE PHYSICAL MODEL

## A. Introduction

Conventional systems analysis techniques such as dynamic programming, linear programming, queueing theory and digital simulation have been very useful to solve various production control problems in manufacturing systems. Except for digital simulation, these techniques do not provide the analyst with the means to assess the real time behavior of manufacturing systems. Digital simulation can very closely represent the real time behavior of manufacturing systms. Digital simulation techniques such as GPSS, GASP, SIMSCRIPT and DYNAMO have significantly advanced the art of systems analysis (3). Deisenroth, Nof, and Meier (31), however, write that digital simulation is abstract because it is difficult to convey results obtained from digital simulation and to convince decision-makers that a proposed design concept is going to achieve their expected goals.

Physical simulation demonstrates physical flow and spatial interaction under various control schemes. Also, a physical model can be disassembled and reconstructed to creatively simulate a large variety of different situations and configurations.

Diesch (3) constructed a model of a flexible manufacturing system. His model simulated the operation of an actual FMS currently being installed by a midwestern manufacturing facility. The model has an AS/RS (Automatic Storage/Retrieval System), a parallel storage structure, a parallel machine center structure, one turning cell with a miniature robot, and two control microprocessors.

The purpose of this chapter is to describe the original configuration of Diesch's model. Significant physical modifications have been made to Diesch's model as part of this research. These modifications are described as well.

## B. Model Configuration Characteristics

### 1. Overview

The physical model was designed to represent an actual automated flexible manufacturing system. The actual FMS is designed to produce seven types of components which do not justify the high tooling investment with transfer lines. The work issued to this FMS will consist of complete manufacturing or operational work on cast iron, ductile iron, and steel parts. The conceptual layout of the FMS (Figure 3-1) shows that the equipment contained in each machining cell consists of the following:

- Machine center cell: 6 CNC machining centers (A1 - A6) with 96 position toolholders;
- Turning cell: 2 CNC vertical lathes (D-1 and D-2), carousel toolholder (D-8), robot (D-3) and wash (D-6);
- Finish machining cell: lap, hone, deburr, and finish equipment.

<u>a. Part flow through the system</u> The backbone of the FMS is an automated storage and retrieval system (AS/RS) (K-1 and K-2) which supplies all parts to machines. The AS/RS contains all the fixtures

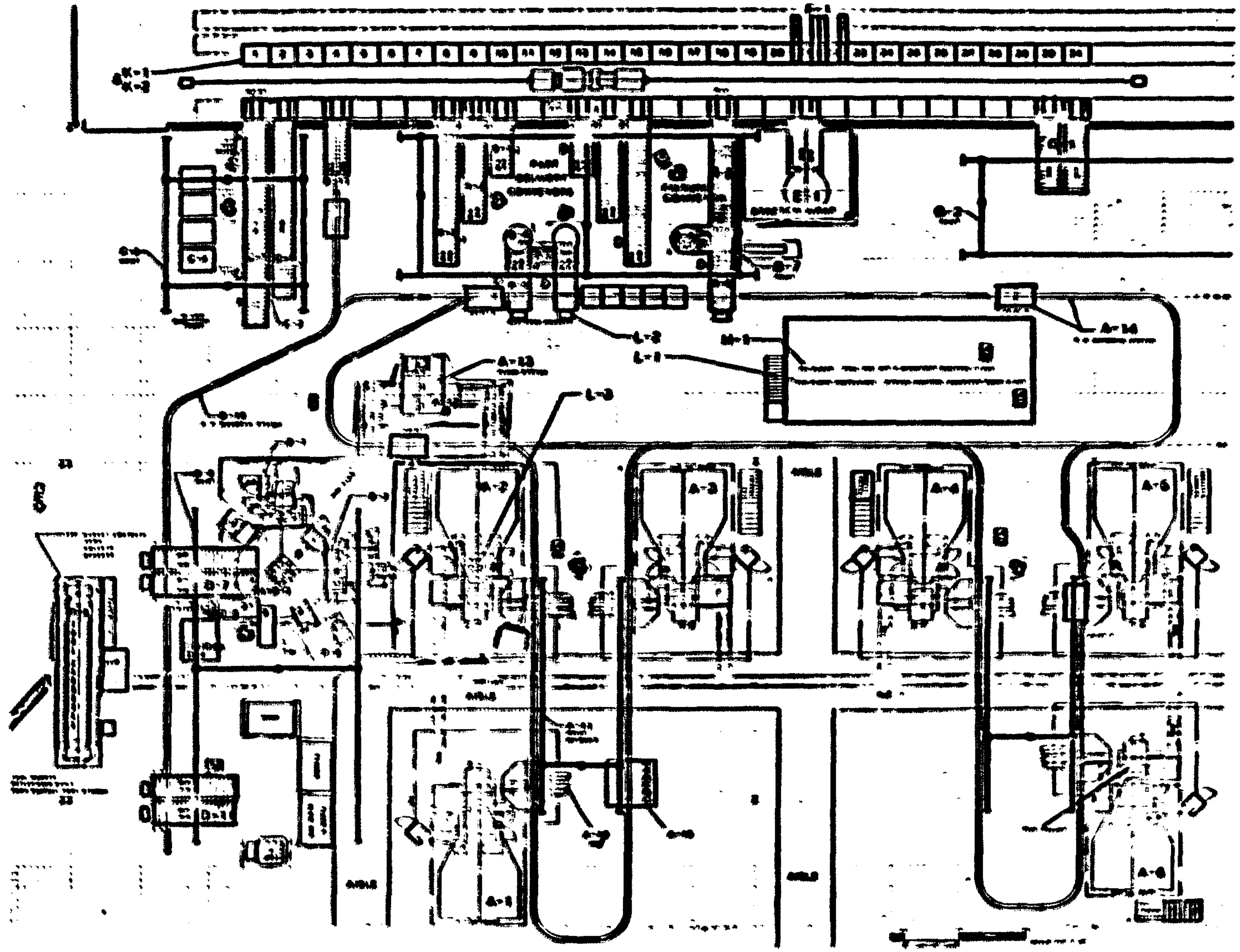



Figure 3-1. FMS conceptual layout

necessary for the machine centers. Castings and semi-finished parts for FMS production are loaded on storage pallets at the input cell (C-1 - C-5). They are then stored in the AS/RS (K-1 and K-2) until scheduled for production. When the parts are scheduled for FMS production, parts are delivered to the machines via an automatic guided vehicle mechanism (AGVM). Loading and unloading of the lathes is performed by a robot (D-3). The machine centers are automatically loaded and unloaded by 180 degree pallet changers (A-10).

The entire system is closed-loop. Part counts are verified on a weigh scale prior to the entrance into the AS/RS. Terminals are located at strategic locations in the system so that operators can enter information regarding scrap, rework, etc. Inspection is performed by automatic inspection equipment.

If parts require additional operations after the machining centers, the parts are scheduled out of the AS/RS and delivered automatically to the finish machining cell. Here, the parts are manually loaded onto lapping, honing, deburring, and washing equipment. When a pallet of parts is completely finished, it is transported automatically to a stretch wrap machine (E-1) and automatically wrapped. Parts are then sent to an exit conveyor (F-1) to be placed in a finished part warehouse.

b. Portions of actual system represented by the model The preceding discussion indicates that the FMS that was modeled is a complicated system. The physical model contains only major sections of the actual system. The major sections include the material handling system, the AS/RS cell, the turning cell, and the machine center cell. To further reduce the complexity of the physical model, the number of part families used in the model was limited to seven. These seven part categories represent each of the seven major part families associated with the actual system.

2. Diesch's original Model

Diesch's model consisted of seven identical storage areas, one semifinished storage area, overhead conveyors, two lifting ramps, an AS/RS cart, six identical machine centers and a turning cell. The turning cell consisted of two vertical lathes loaded/unloaded by a miniature robotic arm (a Mini-Mover-5), and a washing machine. In addition, the model utilized fifteen motorized gates. Eight were used for the storage areas, six for the machine centers, and one for the turning cell finish queue. Seven motorized diverters were also used. Six were used for the machine centers, and one between the turning cell and the machine centers. The gates were used to capture and release parts. The diverters were actuated to select the path of a part through the model.

Figure 3-2 shows an overview of the FMS physical model. Figure 3-3 shows its simplified configuration. According to the configurations, it can be shown that the model is a mixed parallel workstation. Storage areas 1-8 make one set of parallel structures. This means that the model has a multiple input channel for arrivals. Another set of parallel structures is formed by six identical machine

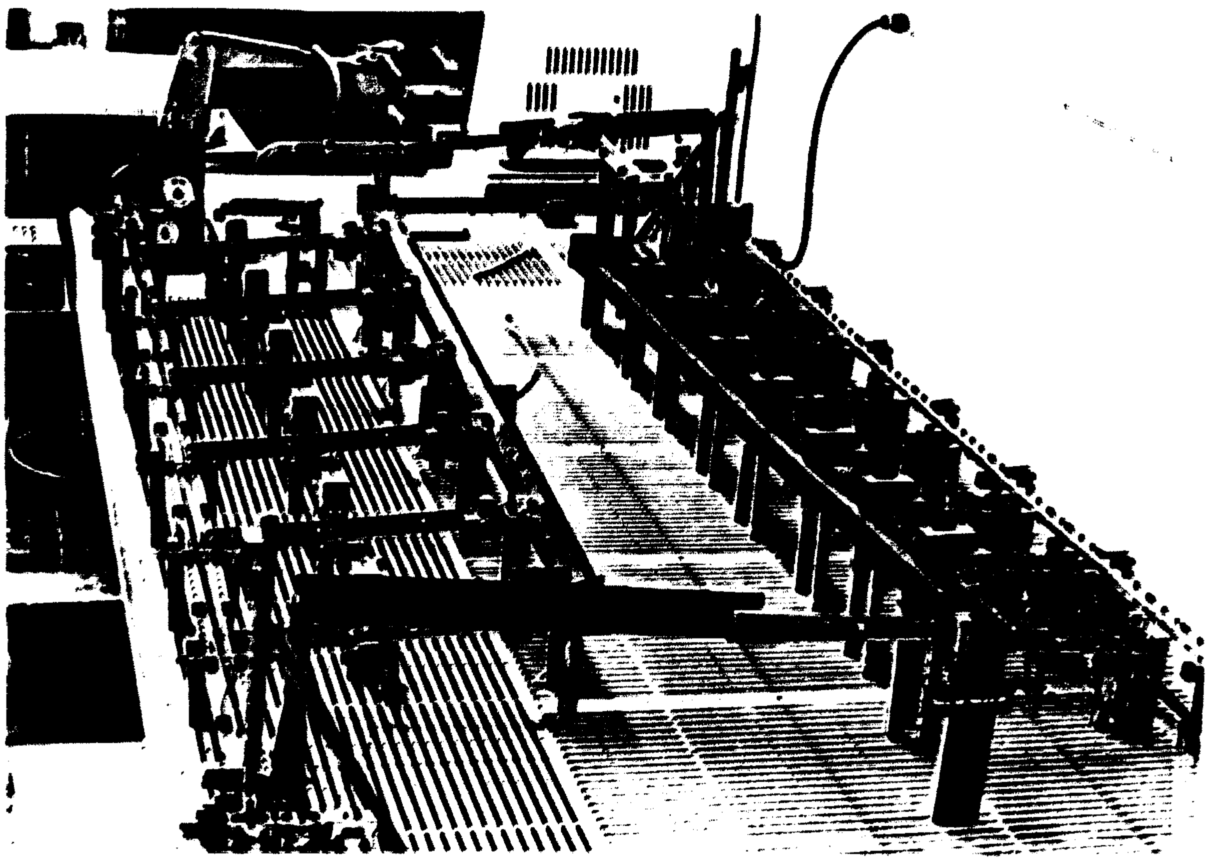


Figure 3-2. Overview of FMS physical model

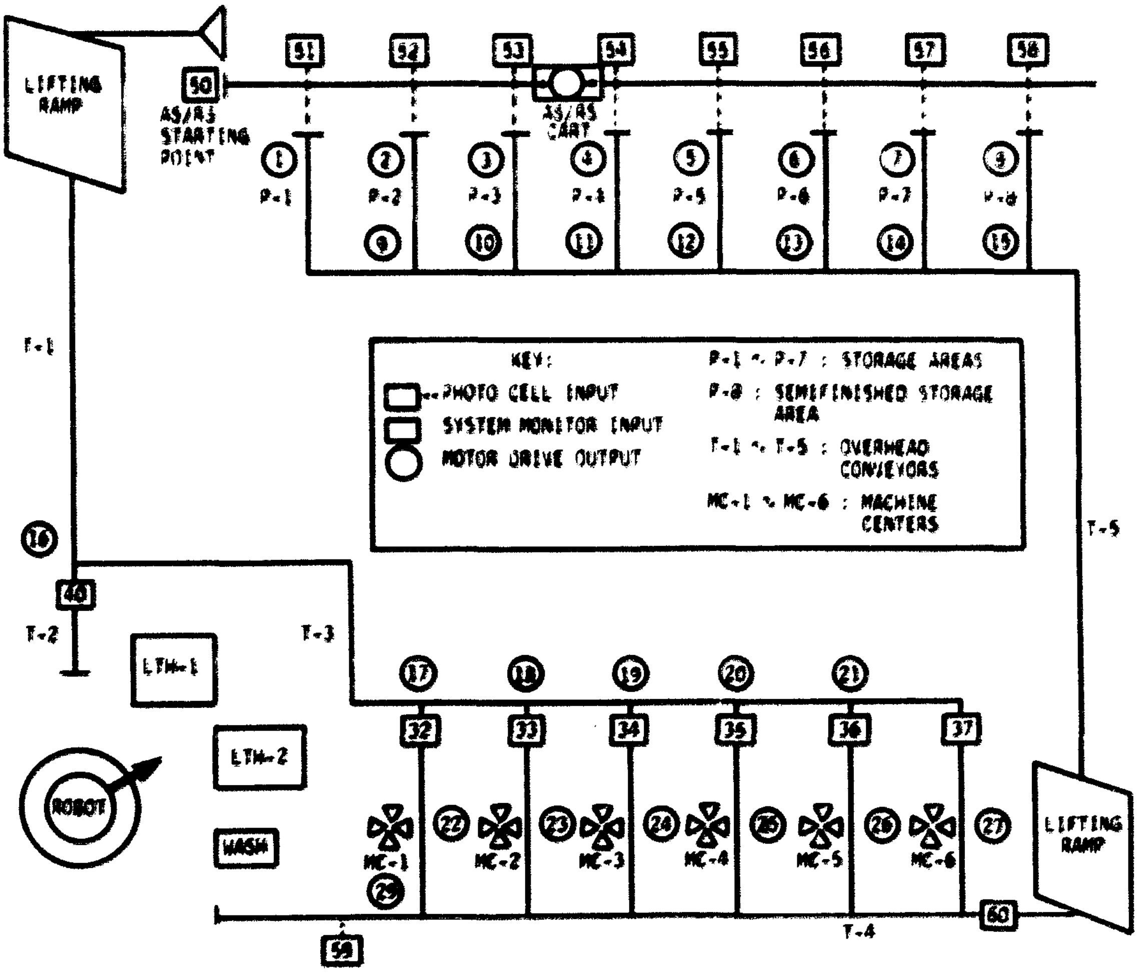



Figure 3-3. Schematic layout of the FMS physical model

centers and the turning cell. Each of the storage areas has a maximum capacity to store 5 parts. Both the machine centers and the turning cell have a maximum queue length of 5 parts.

A part is dispatched from one of the storage areas, and is transported by the AS/RS cart and first lifting ramp. The part is deposited in the waiting line (queue) of the turning cell or one of the machine centers via the overhead conveyor. When an operation is finished, the processed part is released to the overhead conveyor, is elevated by the second lifting ramp, and is stored in its original storage area or the semifinished storage area.

3. Modifications to Diesch's model

Diesch's original model had two types of problems in automatic operations. One was insufficient electrical power that impeded the smooth movements of motorized gates and diverters. The other was a slow retrieval speed of the AS/RS cart. This made it difficult to conduct simulations at rates faster than real time.

Diesch's overhead conveyor routes were subsituted by an AGVM (Automatic Guided Vehicle Mechanism) route without major changes of the original design.

a. Improvements to the model's power source A Commodore CBM 8032 microprocessor controlled the model except for the robot in the turning cell. The turning cell was controlled by a Radio Shack TRS-80 Model III computer. The physical model required 29 output lines and 18 input lines. All of the I/O line must be separately addressable. The Parallel User Port attached at the CBM microprocessor as I/O device for the model control is capable of seven ouput lines and one input line. Diesch expanded the seven output lines and one input line of the CBM to 32 output lines and 32 input lines that are seperately addressable. Diesch used a multiplexer consisting of five integrated circuits (ICs) and a 5 volt, 6 amp power supply. The internal power supply was used to supply current to the multiplexer as well as to supply current to all the gate motors and input circuits.

Problems occurred when output signals were transmitted to output lines (motorized gates and diverters), and input signals were recieved from the output lines. Electrical noise caused a drop in the DC power supply output voltage. The models' gates and diverters were designed to operate at 6 volts. When the 5 volt power source voltage dropped, these devices often failed to move properly or jammed.

The problem was solved when an additional power supply was installed to supply 7 volts independently to each output line. Each of the 29 output lines was supplied with its own circuit board by which the multiplexer's 5 DC volt signals are isolated from the new 7 volt signals from the new power supply. A circuit board consists of one optocoupler (4N33), one triac (T2300A) and two 1K resistors. Figure 3-4 shows an electrical circuit diagram for the circuit board. The circuit isolates the 5 volt multiplexer output from the 7 volt power supply for the model's gates. Upon reception of a 5 volt multiplexer input, a ground is applied to pin 2 of the gate motor, thus applying 7 volts to it. The physical movement of the gate tips the switch shown to turn off the power after the gate has finally opened. This change constitutes a significant modification to Dieech's original circuit design.

b. Speeding up the retrieval process A part processed by a machine center is returned to its original storage area as new raw material. A part from the turning cell became a semifinished part and was stored in the a semifinished storage area (storage aree 8). In the actual FMS, all processed parts are routed to an automatic inspection aree to be inspected. There was no inspection area in the physical model because it was necessary to provide new raw materials automatically to the storage areas. This is a difference between the model and the actual system.

The "return parts" process worked as follows. If there were several parts finished by different workcenters including the turning cell, those parts could not be released simultaneously on the overhead conveyors. This was because only the lifting ramp could return only one part at a time to a storage area. The lifting ramp acted as a bridge between workcenters and the storage areas. Thirty seconds, on the average, were required to complete one return process cycle. This amount of time was relatively high in comparison with the other model operation times. For example, the average fetch time required to fetch a part from storage area was 0.09 minutes.

The problem was solved by installing a new return queue (#60 in Figure 3-3) with its own motorized gate. The new gate was

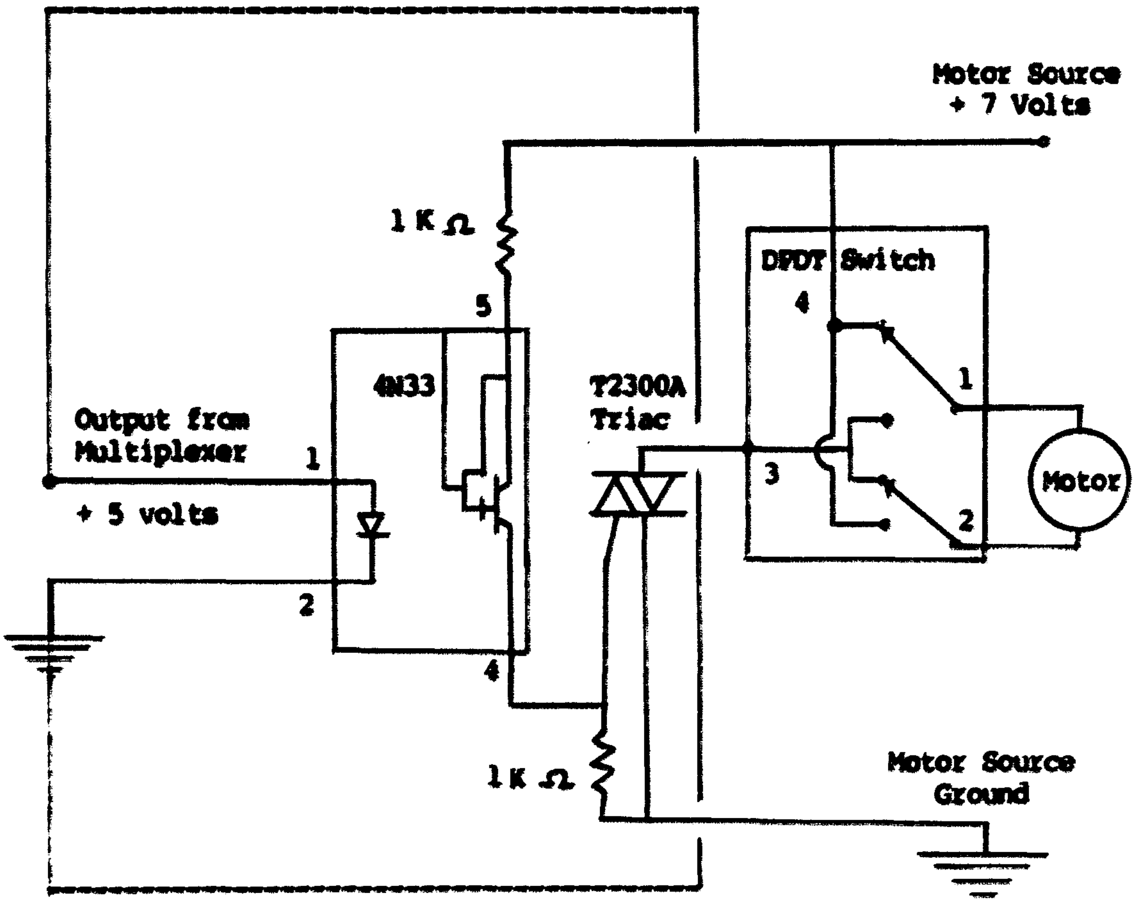



Figure 3-4. Schematic layout of motorized gates and diverters circuit

installed in front of the lifting ramp which served the return process. The maximum queue length of the queue was 5 parts. Whenever a workcenter completed its processing of a part, the part could be released at any time as long as there was at least one available space for the part in the return queue. With this modification, the average return process time was reduced by one half.

c. Automatic Guided Vehicle Mechanism (AGVM) Diesch's model was based on an early conceptual layout of the actual FMS. In the original layout, an overhead monorail system was to be used to transfer parts to workcenters and to retrieve finished parts. The design was later changed by substituting an AGVM for the conveyor. This change did not affect the physical configuration of the model. However, it was necessary to modify part traveling times to reflect the actual FMS travel times required by the AGVM.

d. Modification of the AS/RS cart Diesch's cart travelled on notched track. A Fischertechnik small motor and gear box was attached to the track. In order to supply power to the cart's motor, Diesch used 24 gauge copper wire along each side of the cart for the full length of the track. The average traveling time was 2.2338 minutes. To reduce this time, the design of the cart was changed. The notched track was replaced with a 1.25" by 72" rail. Also, 4 wheels were attached to the cart, replacing the gear box. Power was supplied to the cart's 5 volt motor by utilizing two metal brushes which touched each side of the rail. The average traveling time of the cart was reduced to significantly to 0.09 minutes. Figure 3-5 shows the modified AS/RS cart and its rail.

4. Model characteristics

The modified FMS model is different from a conceptual job shop in various ways. These differences are summarized below.

- Computer-control - Two microcomputers including a Commodore CBM 8032 and a Radio Shack TRS-80 Model III control the model's operation and the robotic arm's movements. The model's operation is therefore automatic.
- Closed-loop operation - A finished part returns to its original storage area as new raw material.
- Multiple input channels - Seven identical storage areas are used. Parts can be randomly stored on each of channels.
- Maximum queue length - The machine centers, the turning cell, and the return queue have a maximum queue length of five parts.
- Transportation time for part transfer - A constant part travel time from a storage area to a machine center or the turning cell, and vice versa exists.
- Breakdowns of major components - Failure of any components can be simulated at any time.

## C. Component Breakdowns

For this research, unplanned downtime events of constant duration were assumed. Failures of major components such as the AS/RS cart, the Mini-Mover-5 in the turning cell and the machine center could be simulated at any time. Several components could fail concurrently during the model's operation. When a breakdown

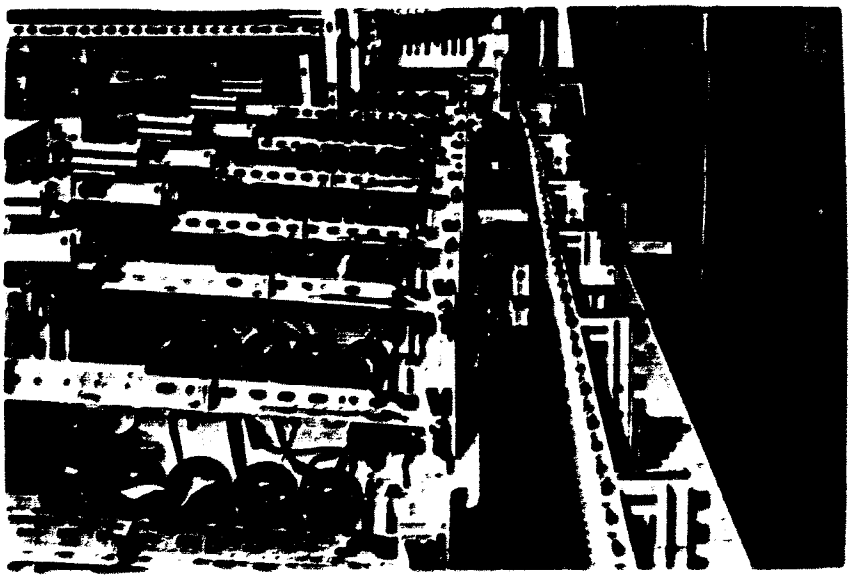


Figure 3-5. New AS/RS cart and rail

occurred, normal operations did not resume until the breakdown was repaired. Detailed descriptions for failures are presented in Chapter 5. Whenever a failure occurred in a major component, the failure time started immediately after the related component finished its work cycle. The work cycle was dependent upon the failed component's performance. Table 3-1 shows the work cycle of the major components on the basis of current performance and failures.

The failure time data include failure occurrence time and duration of the failure. These data were obtained from the actual FMS. The actual data are presented in Chapter 5.

## D. Physical Operation of the Model

### 1. Overview

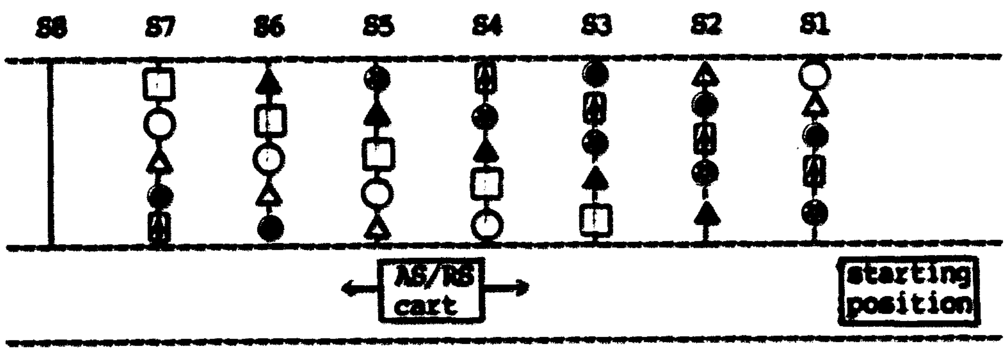
The operation of the model is completely automatic, with the exception of starting it. Parts must be placed in the storage areas at the beginning of the simulation.

### 2. Initialization procedure

At the beginning of each simulation, seven different part families are placed in each of storage areas. Each family consists of five identical parts. Therefore, total number of parts to be allocated to the seven storage areas is thirty-five. In part selection, a specific priority value is assigned to each part. In each part family, parts have the same priority value. Figure 3-6 shows the part allocation method. An exception to this is storage

Table 3-1. The work cycle of failed components

| Failed component | Current performance | Response |
|---|---|---|
| AS/RS cart | contains a part | Waits at the starting position until completion of failure. |
| | contains no part | |
| Mini-Mover-5 | on lathe 1 | When the Mini-Mover-5 fails, the entire turning cell operations stop. Operation resumes after completion of failure. |
| | on lathe 2 | |
| | on washing station | |
| | waiting and idle | |
| One or more machine centers | is processing parts | Continues its current processing. Failure starts immediately after the processing is finished. |
| | idle | Waits until completion of failure. |




. key: S1 - S7: each storage area
S8: semifinished storage area
: part family 1 : part family 2
: part family 3 : part family 4
: part family 5 : part family 6
: part family 7

Figure 3-6. Part allocation method

area 8 which is reserved for semifinished parts. Figure 3-6 illustrates that a row has seven different parts. Each column has a different sequence of the stored parts. The storage arrangement permits the AS/RS cart to access any of the seven part types on any retrieval. In every fetch, computer tries to find a part which has the highest priority.

There are no parts at any other locations in the model at the start of the simulation. The next step in the startup procedure is to load the software programs into the two computers, a Commodore CBM 8032 and a Radio Shack TRS-80 Model III. These software programs are described later.

Once the software is loaded and the required operational parameters are entered into the computers, the robot must be manually positioned on a loading block. With the fixed locating block as a reference point, the robot may execute precise movements according to its control software.

Finally, all of the motorized gates in the model must be closed by entering the appropriate commands on the CBM computer. These commands are also described in a later section.

3. Selecting a part from the model

In the first step of a manufacturing cycle, the control computer (CBM 8032) checks three basic conditions.

- Which machine center has a space on its waiting line for a part?
- Does the turning cell have a space in its input queue for a part?

. Is there a semifinished part on storage area 8?

If the first condition exists, a part which has the highest priority and will be processed on a machine center in the first row of the storage areas of Figure 3-6 is selected. If the second condition exists, the highest priority part which will be processed on the turning cell in the first row of the storage areas is selected. If both conditions exist, the part with the higher priority part is selected. This means that a priority rule is applied whenever there is an available space for a part. If the third condition exists, one of the semifinished parts is selected first. This means that a semifinished part supersedes all priority rules.

One or more parts can have the same priority in the first row of the storage area. In this situation, a part which is stored in the area nearest to the AS/RS cart starting position (Figure 3-6) is selected first. This reduces travelling time for part movement.

The computer sends a signal to the AS/RS cart to fetch the selected part from the storage area. The AS/RS cart begins to move into the AS/RS system as shown in Figure 3-7. While the cart is moving, the computer checks the electric eye at the storage area storing the selected part to determine whether the cart has reached the part load area. When the cart interrupts the light beam at the storage area, the computer sends a signal to the AS/RS cart to stop. A signal is then sent to the motorized loading gate at the storage area. This signal causes the gate to automatically load the selected part onto the cart as shown in Figure 3-8.

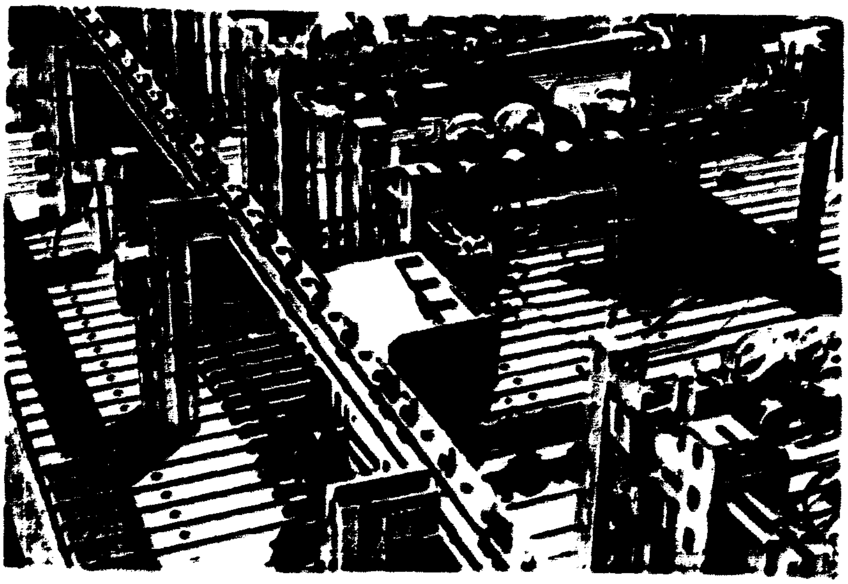


Figure 3-7. Model AS/RS cart fetching part from storage

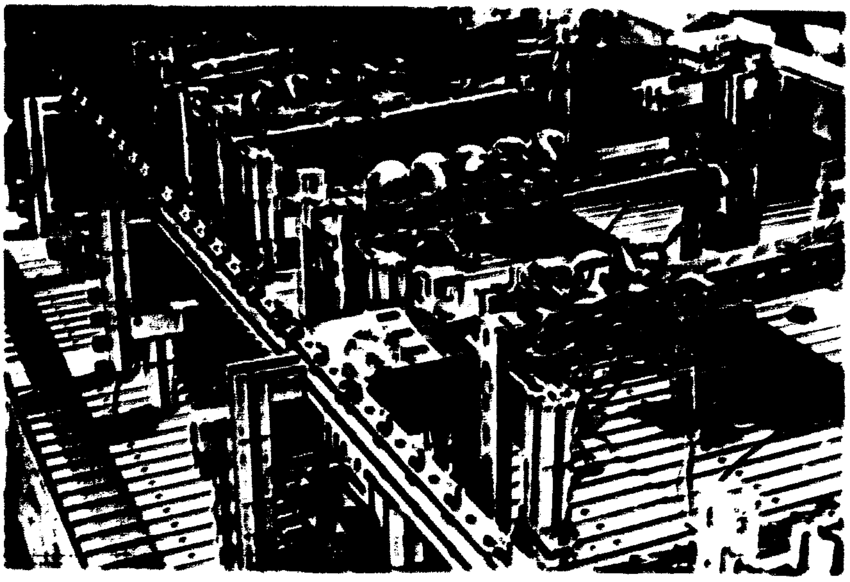


Figure 3-8. Automatic loading of model part

After the part is loaded on the cart, a signal from the computer causes the cart to return to the entrance of the AS/RS starting position as shown in Figure 3-9. When the cart reaches the entrance of the AS/RS starting position, it passes the end of the part holding wall and engages a stop switch. The part then falls from the cart and rolls to the lifting ramp as shown in Figure 3-10. The lifting ramp provides elevation so that the part may move throughout the model by gravity feed. While the lifting ramp is elevating the part (shown in Figure 3-11), the computer decides how the part should be routed according to the part's process routing. Using this information, the computer checks the status of the machine center/turning cell gate (shown in Figure 3-12) and sends a signal to move the gate to the proper position to route the part to the turning cell or a machine center. When the gate is open, the part is routed to the machine center. Otherwise, the part is routed to the turning cell.

In this selection process, the major component is the AS/RS cart. If the cart fails, all selection processes are terminated. When the AS/RS fails unpredictably, the failed cart returns to its original station no matter where it is positioned at the time the failure occurs. This means that the failure starts immediately after the cart finishes its work cycle (refer to Table 3-1).

4. Processing by turning cell

Figure 3-13 shows the beginning of the turning cell's operation. The robot first takes the part from the turning cell input queue and places the part on the first lathe. The robot then starts the

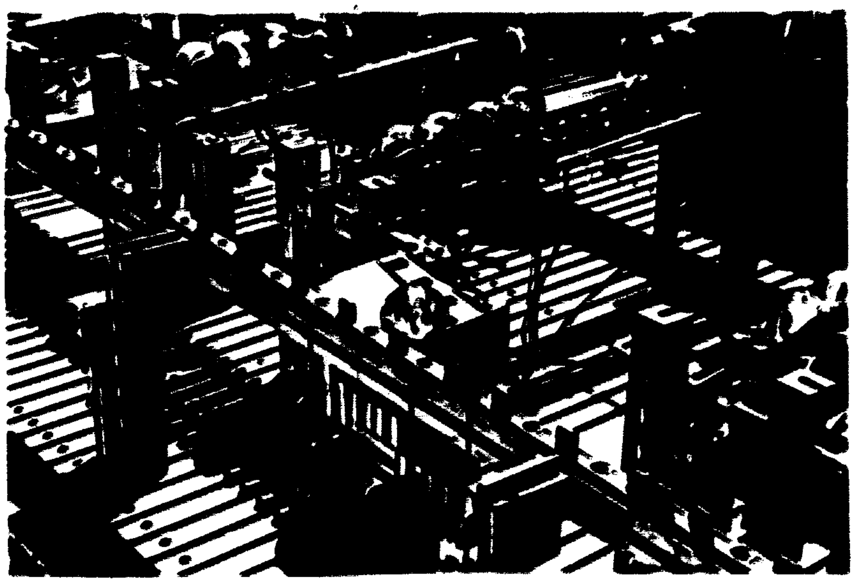


Figure 3-9. AS/RS cart returning with part

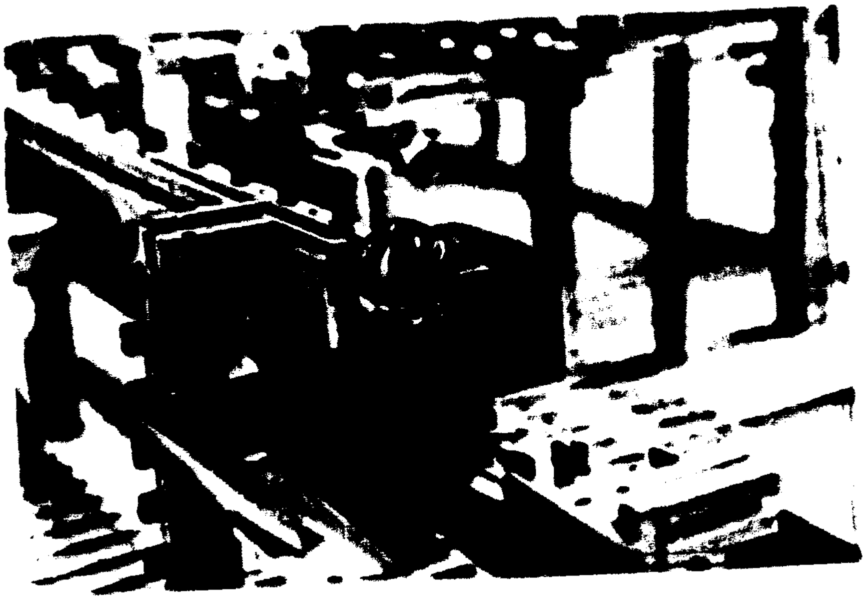


Figure 3-10. AS/RS cart unloading part to lifting ramp

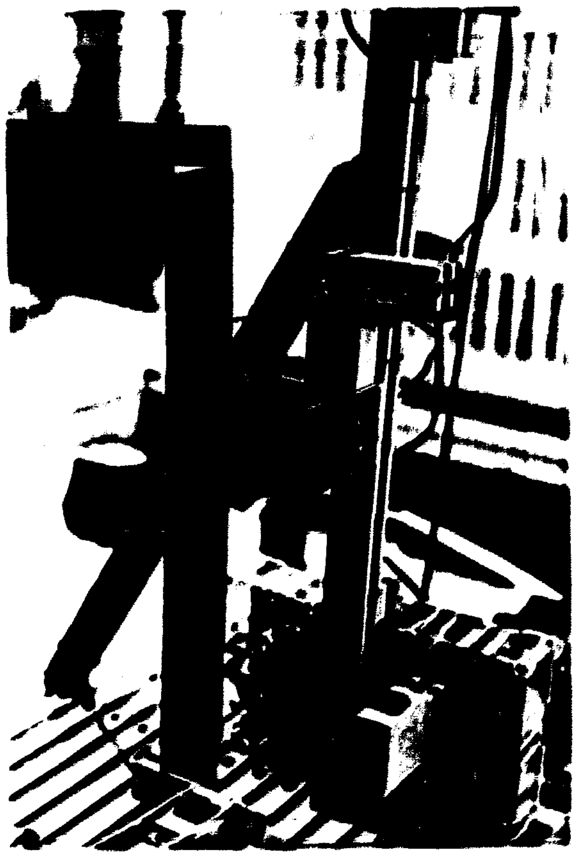


Figure 3-11. Lifting ramp in operation

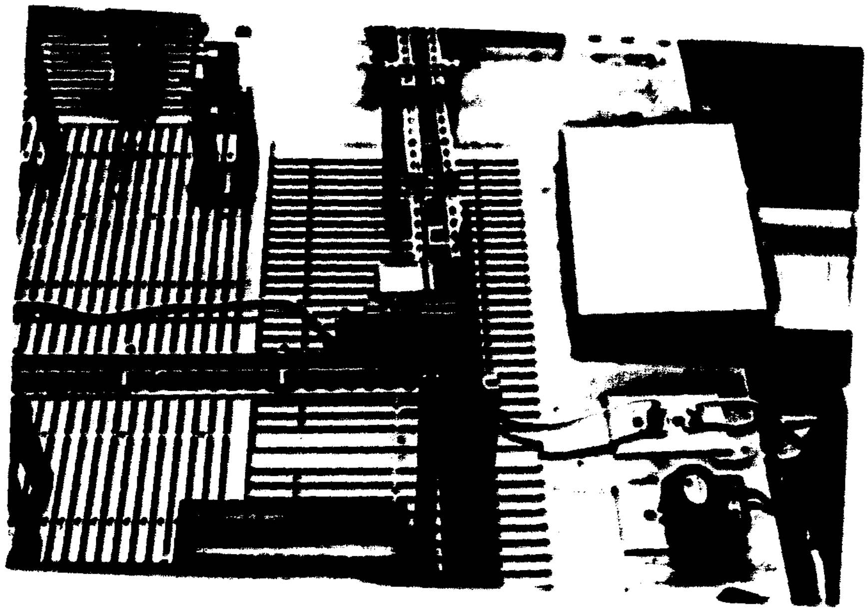


Figure 3-12. Machine center/turning cell gate

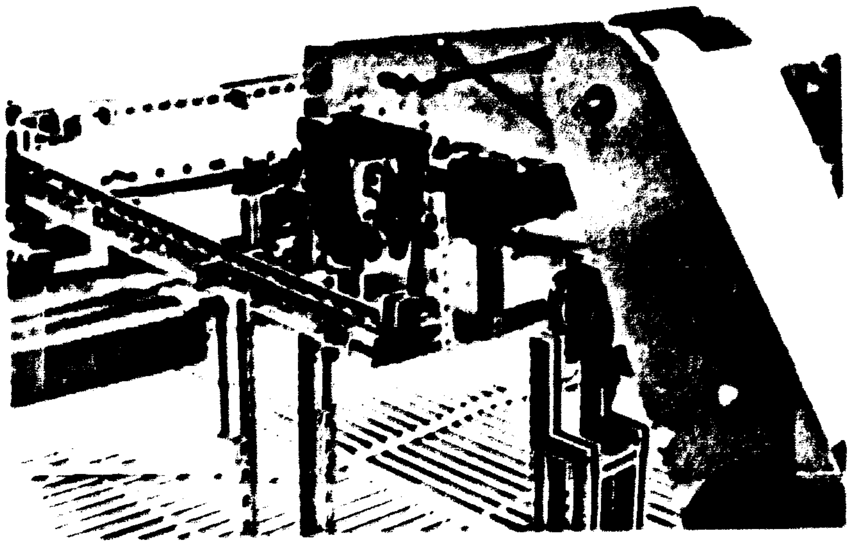


Figure 3-13. Robot taking part from turning cell input queue

machine and moves to a waiting position. The robot waits until the lathe 1's machining cycle is complete. The machining times for the lathes are contained in the robot control software which is described later. When the lathe 1's machining cycle is complete, the robot turns the lathe off and removes the part from the lathe. The same cycle is repeated for lathe 2 as shown in Figures 3-13, 3-14 and 3-15.

The final step in the turning cell operation is to wash the part. Figure 3-16 shows the robot washing the part. When the wash cycle is completed, the robot places the part in the turning cell finish queue (shown in Figure 3-17) and returns to check for another part at the input queue.

In the turning cell, the major component is the Mini-Mover-5. If the robot fails, the entire operation of the turning cell is terminated. When the robot fails, the robot remains its current processing position until completion of the failure. This means that the cell's operation resumes at the position at which the failure originally occurred (refer to Table 3-1).

5. Placement in semi-finished storage area

When the computer detects a part in the turning cell finished queue, a signal is sent to the gate attached to the finished queue (shown in Figure 3-17). The part is then released to AGVM the (automatic guided vehicle mechanism) route and joins a return queue. When released, the part rolls to the return gate attached to the return queue (shown in Figure 3-18) which opens when a second lifting

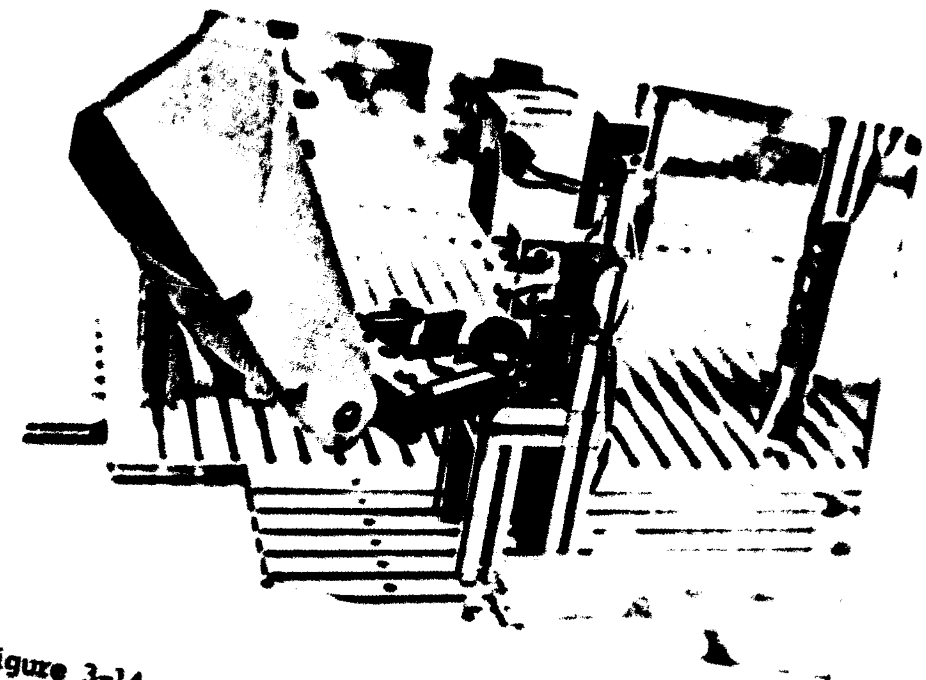


Figure 3-14. Robot loading part on lathe 2

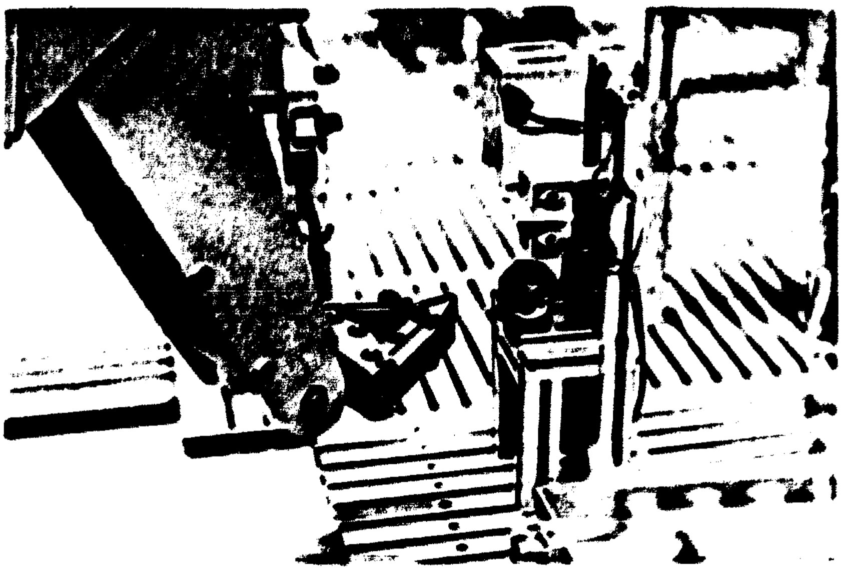


Figure 3-15. Machining in progress on lathe 2

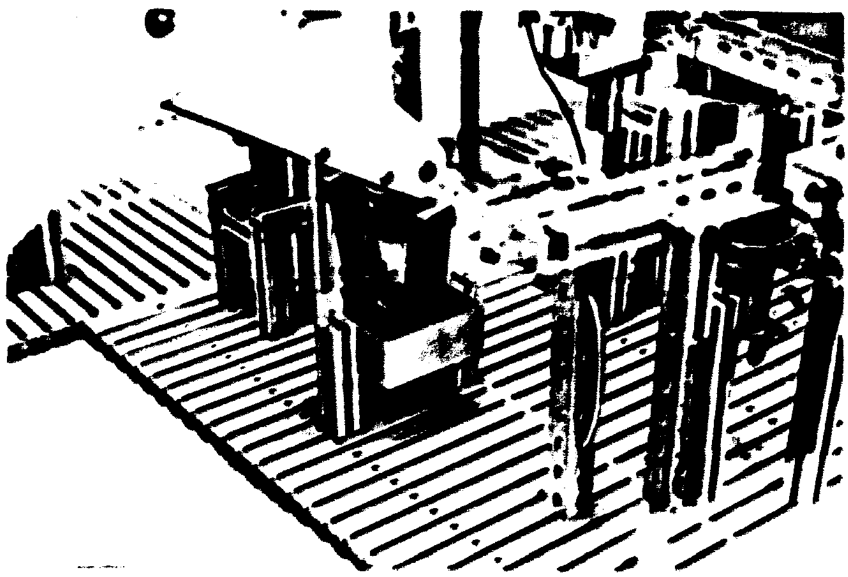


Figure 3-16. Robot washing part

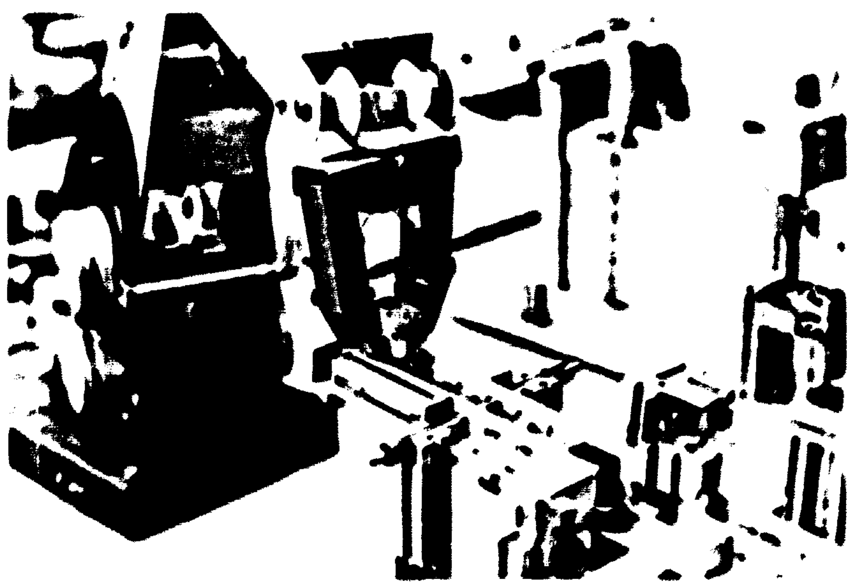


Figure 3-17. Robot placing part in turning cell finish queue

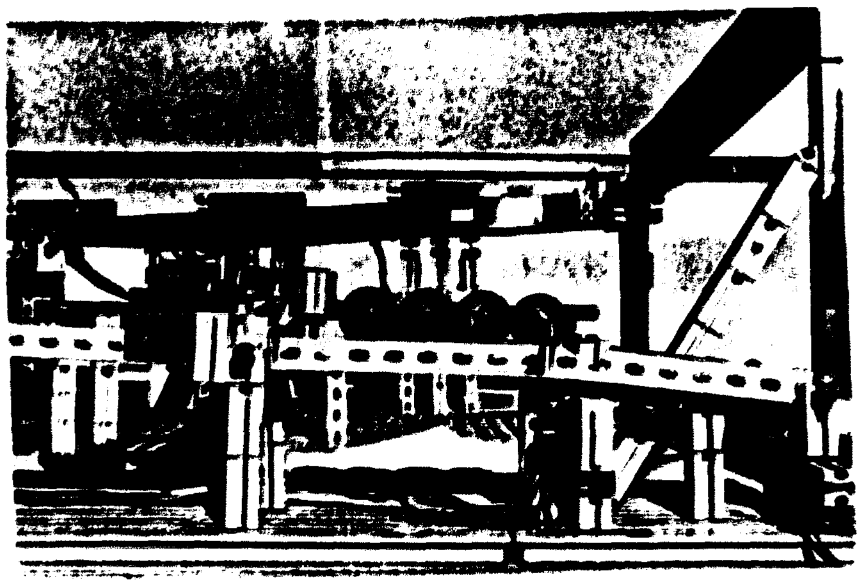


Figure 3-18. Return gate and its queue

ramp (the return lifting ramp) is down. When the return queue is full with five parts, a semifinished part from the turning cell is not released to the AGVM. It is held in the turning cell finished queue until the return queue generates at least one available space for the part. The lifting ramp serves the parts in the return queue on a first come-first serve basis (FCFS).

The return lifting ramp elevates the part in the same manner as the input lifting ramp. While the part is being elevated, the computer checks the status of the part return routing gates. The computer then sends signals to adjust the appropriate gates to return the part to the proper storage area. For example the part is returning as a semifinished part, the part is routed to the semifinished storage area (storage area 8). The computer adjusts storage gate eight as shown in Figure 3-19. When the part reaches the gate, the part is diverted into storage area 8 as shown in Figure 3-20. Figure 3-21 shows the part after it has reached the storage area 8. It is assumed that there are no failures in this part of the system's operation.

6. Processing by machine centers

The next step in manufacturing cycle is machining on one of the machine centers. Each of six machine centers has a priority value determined by a machine center selection rule to be described in Chapter 5. The computer decides which machine center has the highest priority value. However, it should be noted that a part is selected only when a machine center has at least one space on its waiting

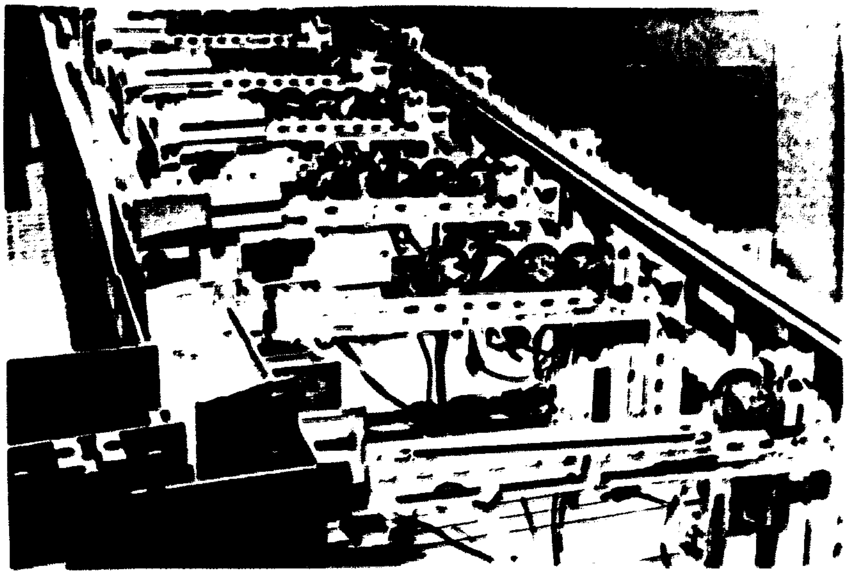


Figure 3-19. Storage gate eight moving to route returning part

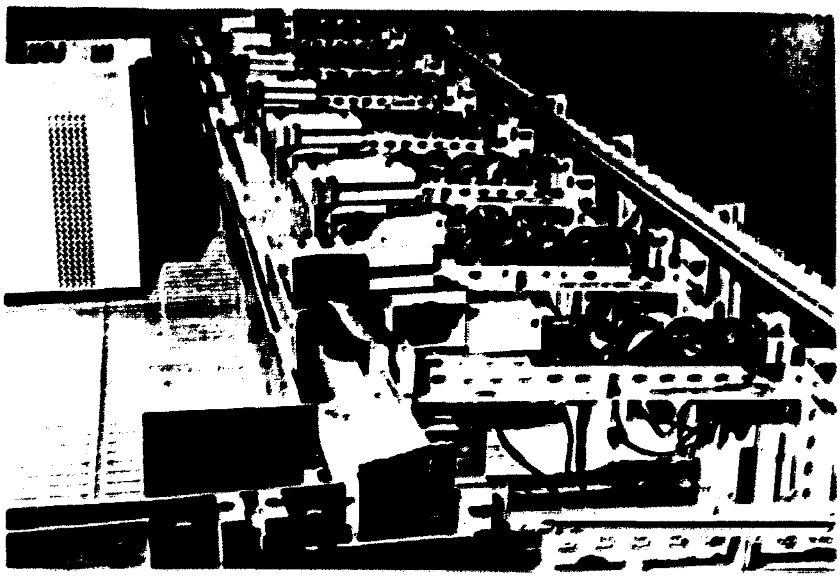


Figure 3-20. Part returning to storage area eight

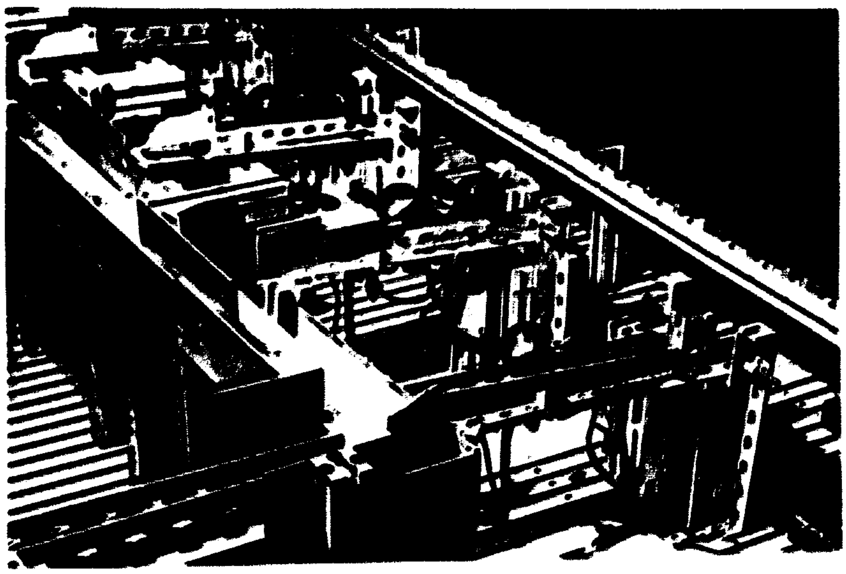


Figure 3-21. Part in storage area eight

line. If the machine center corresponding to the highest priority does not have an available space, the computer tries to find the next highest priority machine which has a space. After both priority and space conditions are satisfied, the part is fetched and elevated by the lifting ramp. Two or more machine centers can have the same priority value. In this case, the machine center nearest to the storage area is selected first so that part traveling time is minimized.

The machine center/turning cell routing gate is moved to route the part to the machine center cell. The routing gate leading to the machine center is moved by the computer as shown in Figure 3-22. Just before the part reaches the machine center, it rolls over a switch which tells the computer that the part has reached the proper machine (see Figure 3-23). Figure 3-24 shows the part being machined on a machine center.

One or more machine centers can fail. Part fetches from the storage area can continue as long as those failed machine centers have available queue spaces. When the spaces of the waiting line become full, the machine center is excluded from priority allocation until it recovers from the simulated failure. If a failure occurs during the processing of a part, the machine center completes in part being processed. The failure begins immediately after the part is completed.

7. Return to storage operations

When the part is finished on a machine center, the computer sends a signal to the machine center gate to release the part as

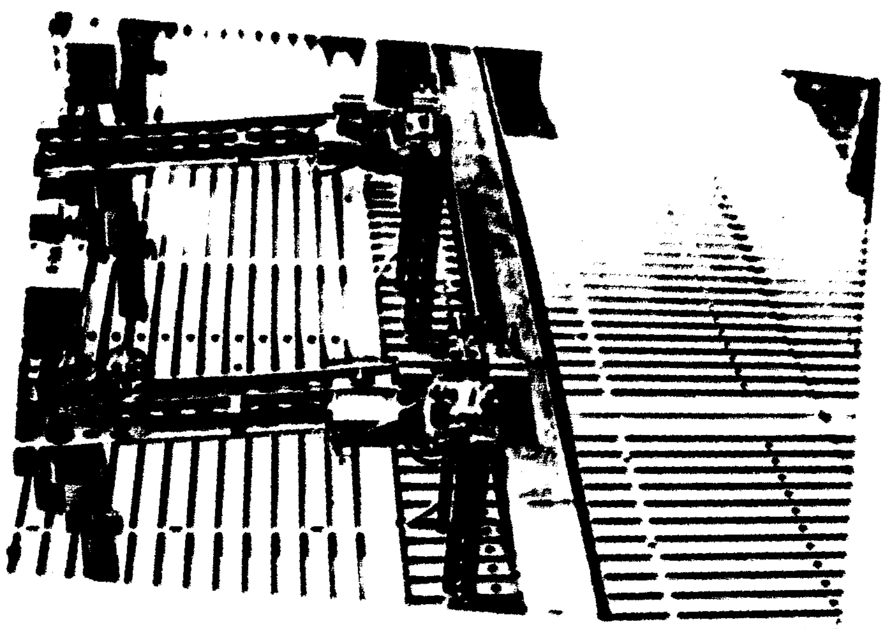


Figure 3-22. Gate routing part to machine center

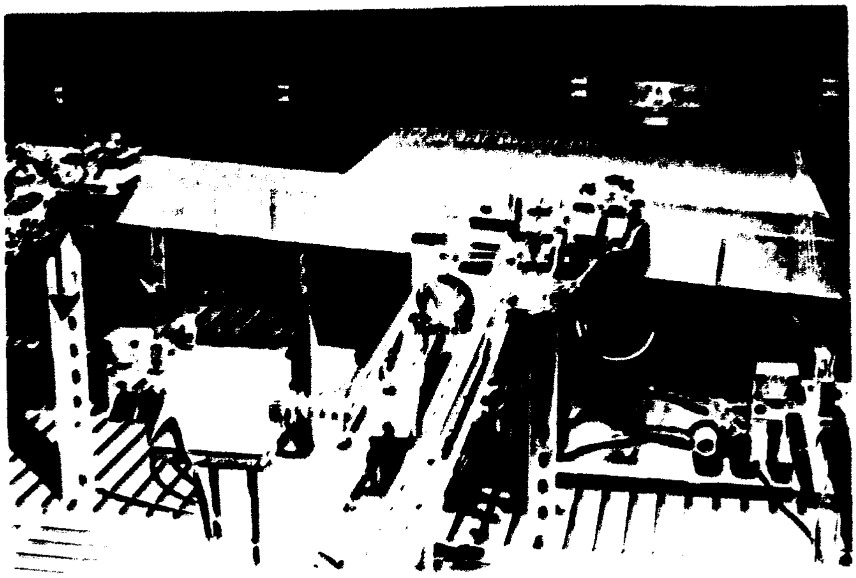


Figure 3-23. Part entering machine center queue

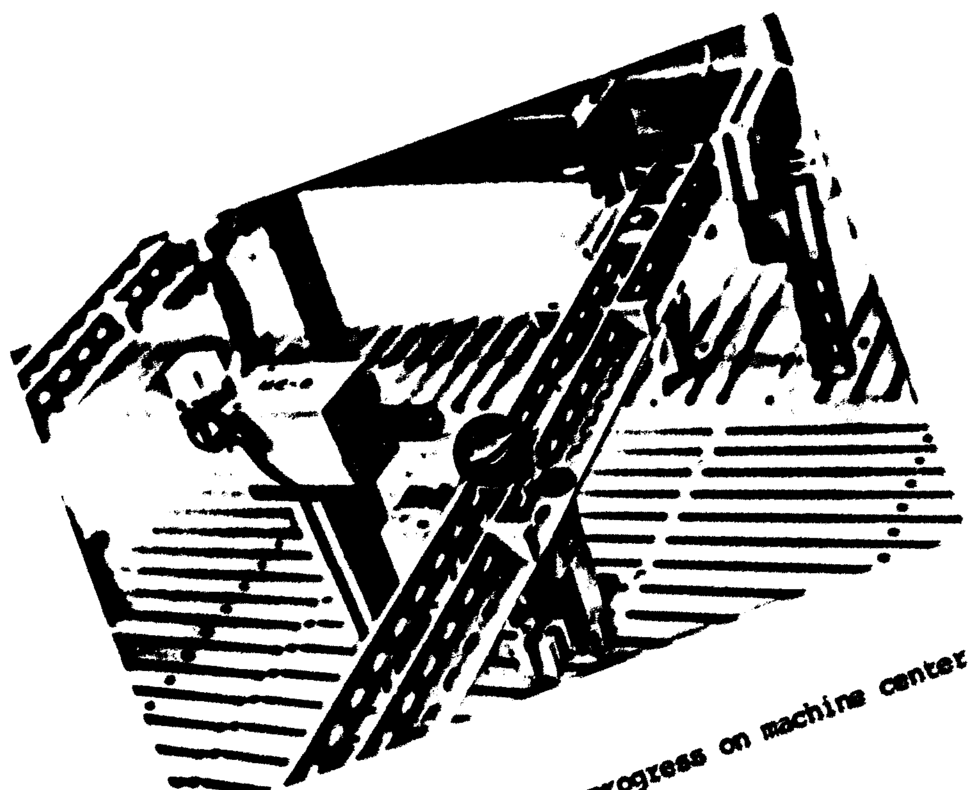


Figure 3-24. Machining in progress on machine center

shown in Figure 3-25. The part then rolls to the return gate (shown in Figure 3-18) and joins a return queue. The part waits until the return lifting ramp is down. After release from the return queue, the part returns to its original storage area to replenish the raw material inventory. In the actual FMS, finished parts would be sent to a finished part storage area.

The lifting ramp can serve only one processed part at a time. Therefore, if several processed parts are awaiting the service of the lifting ramp, a first come-first serve process applies. Figure 3-26 shows the release of the part from the return queue.

The maximum queue length of the return queue is five parts. When work centers try to release their processed parts to the AGVM route, they cannot release the parts if the return queue is currently full. A processed part must wait at its machine center or the turning cell until the return queue has an available space. It is assumed that no failures occur in this part of the model's operation.

## E. Summary

In the above physical operations, some important features can be summarized.

- Parts are allocated to the storage areas through five different sequences of parts in the initialization procedure as shown in Figure 3-6. Thirty-five parts are initially stored in the seven storage areas.

- Whenever a space for a part is available in the waiting line of a machine center or in the input queue of the turning cell, the highest priority part is selected

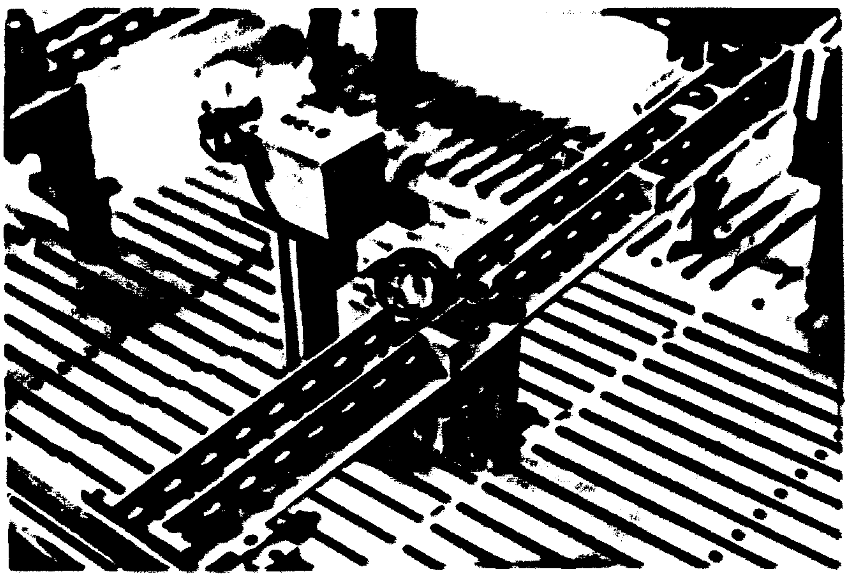


Figure 3-25. Machine center releasing completed part

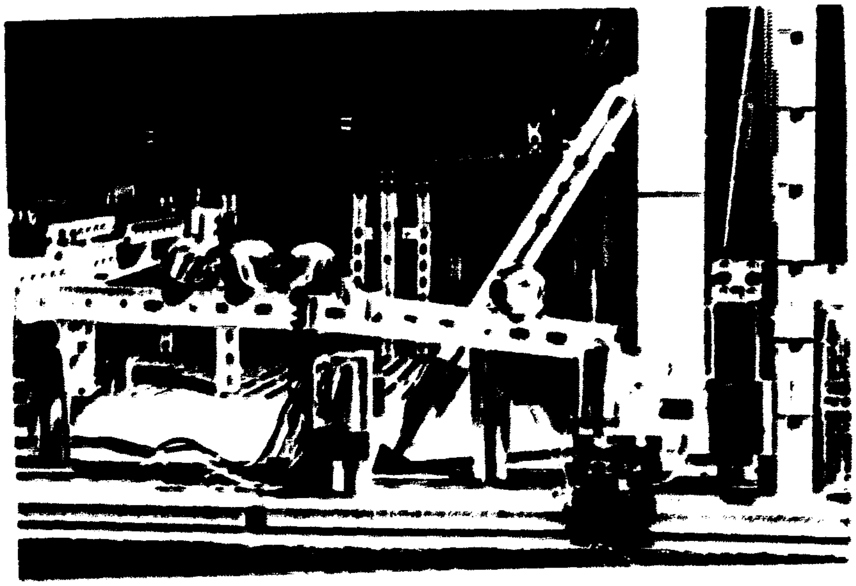


Figure 3-26. Part being released from return queue

first. The priority is determined by the part selection rule in use.

- If there is a semi-finished part in the semifinished storage area (storage area 8), that part is selected first and supercedes any part selection rule priority.

- Each machine center starts processing parts in its waiting line on a first come-first serve basis (FCFS).

- Turning cell selection is dependent upon the process routing of a selected part. Since only one turning cell exists, machine center selection rules do not apply for parts initially routed to the turning cell.

- The robot picks a part up from the turning cell input queue on a first come-first serve basis (FCFS).

- All parts processed by the machine center cell return to their original storage area to replenish the raw material inventory.

- All processed parts by the turning cell return to storage area 8 to await their next operation.

- The following components fail during the simulation. One or more failures can occur simultaneously;

    - The AS/RS cart in the AS/RS cell;

    - The robot (Mini-Mover-5) in the turning cell;

    - One or more machine centers.

- Whenever a workcenter for processing has an available space for a selected part, a part selection procedure continues even though major components may have failed.

Because the physical FMS model is a miniature version of the actual system, it is possible to use actual data in the model's operation. The actual data used include process routings, processing times, traveling times and failure data. The model, however, must use the adjusted time data with scaling factors due to its operational characteristics. This permits the model to operate at rates faster than real time. Time scaling factors are the subject of the following chapter.

# IV. TIME SCALING PROCEDURE

## A. Introduction

Time scaling is a rational way to accelerate the model's operation to rates faster than real time. This chapter describes the scaling procedure adopted in this research.

The physical operation of the model described in Chapter 3 is very complex. However, the entire system operation is dependent on one simple repetitive operation, the AS/RS cart. As a result of the AS/RS cart operation, a part is fetched from a storage area and is provided to a workcenter cell. The same operation occurs in the actual system. Therefore, the fetch time required for the AS/RS cart to fetch can be directly compared with the operation of the actual system.

Part transit or route time is another time factor that must be compared. A route time is defined as a time required for a fetched part to be routed to a machine center or the turning cell.

Both time factors, fetch time and route time, vary with working distance of the AS/RS cart from a storage area and the distance a part must travel to a machine center or the turning cell. These time factors are always constant in every decision rule set that has been evaluated in this research. There is, however, a time factor which varies with a decision rule set.

As mentioned previously, the model has three major cells: the AS/RS cell, the machine center cell and the turning cell. In the actual system, each cell can be controlled separately by control computers. In the physical FMS model, however, only the turning cell is independent. It is solely controlled by the TRS-80 computer. To control both the AS/RS cell and the machine center cell with one microcomputer, the CBM computer, a control link is necessary. A control link is a bridge with which one major cell can determine the other cell's operating status.

This means that the machine center cell's operation is dependent on the AS/RS cell's operation. The machine center cell can start its operation after completion of the AS/RS cell's operation.

Conversely, the AS/RS cell can not start its fetching operation until all necessary machining operations have been completed on the machine center cell at a specific time. The CBM computer needs a delay time during which the AS/RS cell can communicate with the machine center cell through the control link. Each decision rule set performs specific operations in both the AS/RS cell and the machine center cell. The delay time that the CBM computer needs in each decision rule set is then different. The control link is included as subroutines in the model software control programs described later.

The CBM computer controls the finished queue of the turning cell through a photo register attached to the finished queue. The finished queue operation is therefore included in the control link.

The purpose of this chapter is to determine time scaling factors for all decision rule sets by comparing the factors of fetch time, route time and delay time of the model with those of the actual system.

## B. Actual Fetch Time and Model Fetch Time

### 1. Overview

A fetch time is defined as a time required to fetch a part from a storage area. Because the speed of the AS/RS cart is constant, the fetch time is also constant but varies with the distance the cart must travel.

There are three differences between the model and the actual system with respect to the AS/RS. The differences result from differences in mechanical design. To compare an actual fetch time with the model fetch time, these differences must be considered. Table 4-1 describes these differences and subsequent adjustments for the physical model.

### 2. Actual fetch time

An actual fetch time is a pure amount of traveling time required for the AS/RS cart to fetch a part from the AS/RS cell in the actual system. Actual time data were not available because the actual AS/RS was not yet operable at the time, this research was completed.

As shown in Table 4-1, the actual system has thirty-one storage locations. For a consistent comparison of the actual fetch time with the model fetch time , eight storage areas must be equated to the thirty-one storage locations. This is because the model has only eight horizontal storage areas as shown in Figure 3-3.

To estimate the actual fetch time, the following procedures apply:

Table 4-1. Differences in the AS/RS operations

| Actual system | Physical model | Adjustment |
|---|---|---|
| 1. No starting postion. The cart can start from a current position for next fetch. | 1. Existence of a starting position. The cart must return to its starting position. | 1. Existence of a starting position. The cart must return to its starting position. The part delivery conveyor section (B-1 - B-5 in Fig. 3-1) of the actual system is assumed as a starting position. |
| 2. Thirty-one different storage locations in a storage rack system. | 2. Eight different storage areas. | 2. Thirty-one storage locations are equally divided into eight different storage areas for the model on basis of distence. |
| 3. The cart work both horizontally and vertically in fetching a part. | 3. The cart works only horizontally in fetching a part. | 3. The cart's fetch time is assumed to include the amount of time spent for vertical movements. |

- In the conceptual layout shown in Figure 3-1, the actual FMS is scaled down by 0.04375" = 1 ft. Each square is 10 ft. long and 10 ft. wide. The top of Figure 3-1 shows thirty-one storage locations;

- A round trip distance from a middle point of the part delivery conveyor section (B-1 - B-5 in Figure 3-1) to a middle point of each storage location was measured from the conceptual layout;

- The most distant storage area in the actual system is assumed to be Location 31 (160.0 ft.). This corresponds to storage area 8 in the model;

- The average horizontal speed of the AS/RS cart in the actual system is 176 ft./minute. The actual fetch time from Location 31 becomes 0.9091 minutes (160 ft./176 ft. /minute). The model fetch time (known) from storage area 8 is 0.1465 minutes which will be described in the next section. The actual time is slower by a factor of 6.2055 (0.9091/0.1465) than the model fetch time. This means that the actual fetch time should be equal to the known model fetch time * 6.2055;

- Each round trip distance from/to each location in the actual system is divided by the cart's speed to obtain the actual fetch time data. Then, thirty-one actual time values are be compared with eight model fetch times. The final eight locations of the actual system were selected from thirty-one locations utilizing a factor 6.2055. They are presented in Table 4-2.

Table 4-2. Actual fetch time (minutes)

| Storage area | Distance (ft.) | Actual fetch time (min.) | Location in the actual system |
|---|---|---|---|
| 1 | 34.732 | 34.732/176 =0.1973 | between 15 and 16 |
| 2 | 54.613 | 54.613/176 =0.3103 | between 17 and 18 |
| 3 | 70.324 | 0.3996 | between 19 and 20 |
| 4 | 91.419 | 0.5194 | between 22 and 23 |
| 5 | 111.951 | 0.6361 | between 24 and 25 |
| 6 | 123.739 | 0.7031 | between 26 and 27 |
| 7 | 139.257 | 0.7912 | between 28 and 29 |
| 8 | 160.000 | 0.9091 | 31 |

## 3. Model fetch time

A model fetch time is defined as a pure amount of traveling time required for the AS/RS cart to fetch a part from a storage area in the physical model and deposit it on the lifting ramp. To obtain the model fetch time data, the AS/RS cart of the model was moved a total of 3,988 times. Obtained data are presented in Table 4-3.

Table 4-3. Model fetch time (minutes)

| Storage area | Number of observations | Average fetch time (min.) | Standard deviation | Confidence interval (a=0.01) |
|---|---|---|---|---|
| 1 | 425 | 0.0318 | 0.0333 | 0.0276 - 0.0360 |
| 2 | 447 | 0.0500 | 0.0104 | 0.0487 - 0.0513 |
| 3 | 450 | 0.0644 | 0.0097 | 0.0632 - 0.0656 |
| 4 | 692 | 0.0837 | 0.0110 | 0.0826 - 0.0848 |
| 5 | 585 | 0.1025 | 0.0190 | 0.1005 - 0.1045 |
| 6 | 190 | 0.1133 | 0.0154 | 0.1104 - 0.1162 |
| 7 | 215 | 0.1275 | 0.0138 | 0.1251 - 0.1299 |
| 8 | 984 | 0.1465 | 0.0391 | 0.1433 - 0.1497 |

Total number of observations= 3,988.
Average fetch time= 0.09 minutes.

The data were obtained by recording the times to travel to different storage areas. Values for different areas were collected during the debugging of various scheduling subroutines. It is for this reason that the number of observations varies between different storage areas.

The collected data include undesirable fetch time values which occurred due to pauses in the cart's operation. The pauses occurred because of intermittent continuity between the rail and the metal brushes attached to the cart which receive power. The paused cart continued running after being tapped slightly. This is the reason why the standard deviation value of storage area 1 is reasonably high.

## C. Actual Route Time and Model Route Time

### 1. Overview

A route time is defined as a time required for a part selected by the AS/RS cart to be routed to a machine center or the turning cell. The route time is a constant in both the actuel system and the physical model.

There is a difference in routing operations. In the actual system, a limited number of Automatic Guided Vehicles (more than one) provide parts to workcenters. Parts are continuously delivered to workcenters as an AGVS becomes available. In the physical model, however, there is no limitation of available AGVSe. In every fetch, a selected part can be provided to a workcenter unless all workcenter queues are full with previously selected parts. The maximum queue length of a workcenter in the actual system is one part. This length is five parts in the physical model. The difference can be justified when it is assumed that at least one AGVS is always available in every fetch of the AS/RS cart in the model.

### 2. Actual route time

An actual route time is a pure amount of traveling time of a part to be routed to a workcenter in the actual system. These data were not directly available because the actual FMS was being installed during the completion of this research. To estimate the actual route time, the conceptual layout of the actual FMS shown in Figure 3-1 was used. The actual FMS was again scaled down by 0.04375" = 1 ft. in the conceptual layout. Each square is 10 ft. long and 10 ft. wide.

As shown in Figure 3-1, the actual system has six machine centers (A-1 - A-6) which are distributed throughout the system. In the lefthand side of the layout, there is one turning cell (D-1 - D-3, D-6 and D-7). The most distant machine center from the AS/RS cell is machine center A-2. In the physical model, the most distant machine center from the AS/RS cell is machine center 6.

The average speed of an AGVS was known to be 156 ft./minute. Using this speed, actual route times were calculated. They are presented in Table 4-4. Each distance was measured from the part delivery conveyor section to a 180 degree pallet changer (A-10) attached at each machine center. The pallet changer works to automatically load and unload a part on a machine center. The distance to the turning cell was measured from the input cell (C-1 - C-5) to the input conveyor (D-7) of the turning cell.

3. Model route time

A model route time is a pure amount of traveling time for a part to be routed to a machine center or a turning cell in the model. This time is measured from the AS/RS cart's starting position to each workcenter's input queue. It includes a lifting ramp operating time (0.1 minutes) to elevate a part to the AGVM (Automatic Guided Vehicle Mechanism) route. Model route times are presented in Table 4-5. The confidence intervals are computed using Student t distribution with 9 of degrees of freedom due to small sample sizes (32).

Table 4-4. Actual route time (minutes)

| Machine center | Distance (ft.) | Actual route time (min.) |
|---|---|---|
| 1 (A-5) | 152.35 | 0.9766 |
| 2 (A-6) | 176.47 | 1.1312 |
| 3 (A-3) | 216.47 | 1.3876 |
| 4 (A-4) | 256.12 | 1.6290 |
| 5 (A-1) | 299.41 | 1.9193 |
| 6 (A-2) | 328.24 | 2.1041 |
| Turning cell | 87.36 | 0.5600 |

Table 4-5. Model route time (minutes)

| Machine center | Number of observations | Average route time (min.) | Standard deviation | Confidence interval (a=0.01) |
|---|---|---|---|---|
| 1 | 10 | 0.2017 | 0.0042 | 0.1974 - 0.2060 |
| 2 | 10 | 0.2173 | 0.0037 | 0.2135 - 0.2211 |
| 3 | 10 | 0.2275 | 0.0038 | 0.2236 - 0.2314 |
| 4 | 10 | 0.2327 | 0.0030 | 0.2296 - 0.2358 |
| 5 | 10 | 0.2427 | 0.0035 | 0.2391 - 0.2463 |
| 6 | 10 | 0.2581 | 0.0048 | 0.2532 - 0.2630 |
| Turning cell | 10 | 0.1229 | 0.0040 | 0.1188 - 0.1270 |

## D. Delay Times in the Automatic Storage/Retrieval System (AS/RS)

### 1. Overview

The control link was a bridge by which the AS/RS cell could communicate with the machine center cell. The link was necessary because only one computer, the CBM 8032, controlled both the AS/RS cell and the machine center cell.

Each decision rule set must have a specific delay time to activate the control link. At a specific simulation time, a decision rule set performs different operations in both the AS/RS cell and the machine center cell in comparison with the other decision rule sets.

Whenever the cart stops at its starting position (#50 in Figure 2-3) to unload the fetched part, the current system operation status is updated to prepare for next fetch operation. The AS/RS operation can be divided into the following operating factors:

- Traveling to a storage area selected by a part selection rule;
- Loading a part from the storage area;
- Returning to the starting position;
- Unloading the selected part at the starting position;
- Waiting at the starting position until the next fetch operation. The control link works for subroutines of the model control software during this wating time.

The model fetch time described in Section B is a pure amount of time required for the AS/RS cart to travel to a storage area and to return to its starting position. There are two types of delays in the AS/RS operation: one for loading a part and the other for both unloading a part and waiting at the starting position to update the current system operating status (work for the control link). The former is called "DELAY-1", and the latter is termed "DELAY-2".

2. DELAY-1

DELAY-1 is the amount of waiting time per fetch required to load a part to the cart and to check to see if a lifting ramp is ready to serve next fetched part. Loading a part to the cart is achieved by a motorized gate attached at a storage area. When the CBM computer sends a signal to open a motorized gate, a part is ready to be dumped on the cart. According to next signal from the computer, the gate closes, and the part is loaded to the AS/RS cart. The cart is then ready to leave to its starting position.

It takes 0.1 minutes for the computer to complete this task. During this loading procedure, the lifting ramp is checked if it is ready to lift a fetched part. The lifting ramp must be in the down position for every fetched part. Because of high utilization of the lifting ramp a constant delay is used. It takes an average 0.1 minutes for the lifting ramp to elevate a part. It also takes 0.1 minutes to return to its down position. The AS/RS cart must stay at a storage area until the lifting ramp returns to the down position. This takes 0.1 minutes.

As a result, DELAY-1 is always a constant at 0.2 minutes (0.1 minutes for a gate operation and 0.1 minutes for the lifting ramp) in every fetch.

3. DELAY-2

DELAY-2 occurs in the actual system and is different from the model. In the actual system, a fetched part is provided to a work-center after a 7 minute delay. This occurs in the part delivery conveyor section (B-1 - B-4 in Figure 3-1) or the input cell (C-1 - C-5 in Figure 3-1). The DELAY-2 value is thus 7 minutes in the actual system. During this delay time, a crew transfers the fetched part to the delivery fixture.

In the model, DELAY-2 is the amount of waiting time per fetch required to unload a part at the cart's starting position and to update the current system operating status. After DELAY-2, the cart can fetch the next part.

Unloading a part from the cart is accomplished automatically as soon as the cart arrives at its starting position. The top of the cart has a slide to drop the part on the lifting ramp in less than one second.

As soon as the cart returns to the starting position, the CBM computer checks the following system operating conditions:

- Should the motorized gate between the turning cell and the machine center cell be opened for a fetched part? (Open for routing to the turning cell and closed for routing to the machine center cell.);
- Which machine center should open its motorized diverter to receive a fetched part?
- Which machine center should start processing of its next part? A motorized gate attached at the machine center lowers to start processing;
- Which machine center should finish processing of its current part? A motorized gate attached at the machine center rises to release the processed part;
- Is there a semi-finished part in the turning cell finished queue? A motorized gate attached at the queue lowers/rises to release the semi-finished part;
- Which part should return to a predetermined storage area from the return queue? Which storage area should open its motorized diverter to receive the part?

These questions arise in every fetch under normal system operating conditions. The CBM computer needs some amount of time to check these questions and update the current operating status. The total amount of time required to check and update is included in DELAY-2.

The questions related to failures of major components are not included in the above check points. This means that failure checking time is not considered in determining the DELAY-2 value.

In addition, the CBM computer updates all simulation statistics related to the above check points. This updating time is included in DELAY-2.

Each decision rule set generates a specific DELAY-2 value. Each decision rule set has different operating conditions at different time segments when compared with other decision rule sets. In this research, each decision rule set was simulated for over 11 hours. Therefore, the exact DELAY-2 value must be obtained by considering all combinations of possible operations in a 11-hour simulation run under a specific decision rule set. However, an exact simulation time for a decision rule set is also a function of a time scaling factor which in itself contains DELAY-2. The time scaling factor is described in next section.

In this research, the DELAY-2 value was estimated after the model operations entered a stable condition. When all workcenters are busy processing parts, the model can be considered to be in steady state condition. This stable condition was achieved after 2 hours. Therefore, a DELAY-2 value was obtained after 2-hour time simulation for every decision rule set.

Table 1-1 in Chapter 1 shows twenty-eight decision rule sets that have been evaluated in this research. The detailed descriptions of each set are presented in Chapter 5. Table 4-6 presents the obtained DELAY-2 values for the twenty-eight decision rule sets. According to Table 4-6, the average DELAY-2 value for all twenty eight decision rule sets is 0.1972 minutes. The overall standard deviation is 0.0136. The S/PT/WINQ rule set (Set 24) is the most complex rule set. It has the highest value of DELAY-2 (0.2239 minutes). A comparatively simple set, the RANDOM/FMFS rule set (Set 2), has the lowest value (0.1717 minutes). This means that the complex rule sets require longer waiting times to be ready to fetch the next part at the AS/RS cart's starting position.

## E. Time Scaling Factors for Decision Rule Sets

### 1. Overview

A time scaling factor is used to adjust simulation input information such as part processing time, due-dates, failure data (mean time between failures and mean down time), and simulation run time. The determination of a scaling factor is based on actual FMS data.

A scaling factor of a decision rule set can be obtained with values of fetch time, route time, DELAY-1 per fetch and DELAY-2 per fetch. These values have been described in preceding sections.

In the model, there are eight different fetch time values for eight different storage areas. Seven different route time values exist for the six machine centers and the turning cell. Also, the

Table 4-6. DELAY-2 value for twenty-eight decision rule sets

| Set | Part selection rules | Machine center selection rule | Number of observations | DELAY-2 (min.) | Standard deviation | Confidence interval (a=0.01) |
|---|---|---|---|---|---|---|
| 1 | | RANDOM | 162 | 0.1768 | 0.0777 | 0.1611-0.1925 |
| 2 | RANDOM | FMFS | 168 | 0.1717 | 0.0893 | 0.1540-0.1894 |
| 3 | | NINQ | 163 | 0.1846 | 0.0746 | 0.1696-0.1996 |
| 4 | | WINQ | 159 | 0.1970 | 0.0656 | 0.1836-0.2104 |
| 5 | | RANDOM | 163 | 0.1846 | 0.0889 | 0.1667-0.2025 |
| 6 | FSFS | FMFS | 167 | 0.1796 | 0.0782 | 0.1640-0.1952 |
| 7 | | NINQ | 163 | 0.1907 | 0.0647 | 0.1777-0.2037 |
| 8 | | WINQ | 160 | 0.2019 | 0.0659 | 0.1885-0.2153 |
| 9 | | RANDOM | 161 | 0.1961 | 0.0768 | 0.1805-0.2117 |
| 10 | SPT | FMFS | 165 | 0.1818 | 0.0749 | 0.1668-0.1968 |
| 11 | | NINQ | 160 | 0.1993 | 0.0662 | 0.1858-0.2128 |
| 12 | | WINQ | 156 | 0.2100 | 0.0615 | 0.1973-0.2227 |
| 13 | | RANDOM | 162 | 0.1986 | 0.0780 | 0.1829-0.2143 |
| 14 | DDATE | FMFS | 162 | 0.1916 | 0.0864 | 0.1742-0.2090 |
| 15 | | NINQ | 159 | 0.2050 | 0.0672 | 0.1913-0.2187 |
| 16 | | WINQ | 158 | 0.2151 | 0.0645 | 0.2019-0.2283 |
| 17 | | RANDOM | 158 | 0.2103 | 0.0742 | 0.1951-0.2255 |
| 18 | SLACK | FMFS | 160 | 0.2051 | 0.0765 | 0.1896-0.2206 |
| 19 | | NINQ | 158 | 0.2156 | 0.0703 | 0.2012-0.2300 |
| 20 | | WINQ | 156 | 0.2120 | 0.0662 | 0.1984-0.2256 |
| 21 | | RANDOM | 159 | 0.2028 | 0.0757 | 0.1874-0.2182 |
| 22 | S/PT | FMFS | 162 | 0.1945 | 0.0788 | 0.1786-0.2104 |
| 23 | | NINQ | 157 | 0.2106 | 0.0755 | 0.1951-0.2261 |
| 24 | | WINQ | 154 | 0.2239 | 0.0712 | 0.2092-0.2386 |
| 25 | | RANDOM | 164 | 0.1827 | 0.0776 | 0.1671-0.1983 |
| 26 | VALUE | FMFS | 167 | 0.1780 | 0.0838 | 0.1613-0.1947 |
| 27 | | NINQ | 161 | 0.1962 | 0.0725 | 0.1815-0.2103 |
| 28 | | WINQ | 158 | 0.2065 | 0.0643 | 0.1934-0.2196 |

DELAY-1 value is defined as a constant. Twenty-eight different DELAY-2 values are defined for twenty-eight different decision rule sets.

Under a decision rule set, the total number of possible time scaling factors is fifty-five. A total of 48 paths exist from the eight storage areas to the six machine centers. Seven paths exist from storage areas 1 through 7 to the turning cell. Parts from storage area 8 are always routed to a machine center.

The model has six machine centers, eight storage areas and the turning cell. Suppose "i" is defined as the index of a storage area and "j" is defined as the index of a machine center or the turning cell. Each path (i,j) generates a time scaling factor. The scaling factor is defined by Equation 4-1.

$$SF(i,j) = \frac{AF(i) + AR(j) + ADELAY\text{-}1 + ADELAY\text{-}2}{MF(i) + MR(j) + MDELAY\text{-}1 + MDELAY\text{-}2} \qquad (4\text{-}1)$$

where

SF(i,j) = a time scaling factor for path (i,j);
AF(i) = an actual fetch time value from storage area i;
AR(j) = an actual route time value to machine center j;
ADELAY-1 = an actual DELAY-1 value (= 0.0 minutes);
ADELAY-2 = an actual DELAY-2 value (= 7.0 minutes);
MF(i) = a model fetch time value from storage area i;
MR(j) = a model route time value to machine center j or the turning cell;
MDELAY-1 = a DELAY-1 value of the model (= 0.2 minutes);
MDELAY-2 = a DELAY-2 value of the model (shown in Table 4-6);

i = a storage area (i= 1,2,3,---,8);
j = a machine center (j= 1,2,3,---,6: j=7 for the turning cell);

When a semi-finished part is selected from storage area 8 (i=8), the part cannot be routed to the turning cell (j=7). The part must be processed by a machine center. The fifty-five SF(i,j) values for every decision rule set are presented in Appendix A.

2. Normalization delay (ND)

A decision rule set has 55 possible time scaling factor values. The minimum scaling factor value among the 55 values is used for a decision rule set. The minimum value is called by the overall time scaling factor. The overall time scaling factor always corresponds to the path (8,2) for every decision rule set.

Within a specific rule set, constant values of DELAY-1 and DELAY-2 apply. For any storage area, the fetch time is also constant. The remaining variable that determines the longest path is the model route time. Surprisingly, the longest route time is not from storage area 8 to machine center 6. Instead, the longest route time is from storage area 8 to machine center 2.

The downward slope of the model's delivery chute to the machine centers is variable. The speed of delivered parts is small by the time they reach machine center 2. As parts pass this location, they accelerate and therefore reach machines 3 through 6 in slightly shorter times. This time difference is slight and is on the order of 2 seconds or less (refer to Appendix A).

Utilizing the overall scaling factor, the minimum operating speed can be uniformly maintained in the model's operation. However, each path (i,j) must have a normalization delay value to account the difference between the time scaling factor values generated by fifty-five paths. Use of the normalization delay value enables a decision rule set to maintain a constant overall time scaling factor. The normalization delay of a path is defined by Equation 4-2. The first term of Equation 4-2 is the time required for a path (i,j) to maintain the overall minimum time scaling factor under a decision rule set. The second term is the time of a path (i,j) greater than the minimum value. For each decision rule set, these paths are the remaining 54 scaling factors as shown in Appendix A.

$$ND(i,j) = \frac{AF(i) + AR(j) + ADELAY\text{-}1 + ADELAY\text{-}2}{SF_{min}} - (MF(i) + MR(j) + MDELAY\text{-}1 + MDELAY\text{-}2) \quad (4\text{-}2)$$

where

ND(i,j) = normalization delay value of path (i,j) (min.);
AF(i) = actual fetch time from storage area i;
AR(j) = actual route time to machine center j or the turning cell;
ADELAY-1 = actual DELAY-1 value (= 0.0 minutes);
ADELAY-2 = actual DELAY-2 value (= 7.0 minutes);
MF(i) = model fetch time from storage area i;
MR(j) = model route time to machine center j or the turning cell;
MDELAY-1 = DELAY-1 value of the model (= 0.2 minutes);
MDELAY-2 = DELAY-2 value of the model (shown in Table 4-6);

$SF_{min} = \min_{all\ i,j} SF(i,j)$

= the overall time scaling factor of a decision rule set;
i= a storage area (i= 1,2,3, — 8);
j= a machine center (j= 1,2,3, — 6:
j= 7 for the turning cell).

By adding the value of ND(i,j) to the sum of MF(i), MR(j), MDELAY-1 and MDELAY-2, all paths have the same time scaling factor. In the model's operation, this normalization delay is actually added to the DELAY-1 value described earlier. The DELAY-1 value of 0.2 minutes is increased with a normalization delay for each decision rule set. This delay varies with each (i,j) path.

Appendix A shows the ND(i,j) values for all possible paths. According to Appendix A, the minimum time scaling factor always corresponds to (8,2). The value of normalization delay for path (8,2) is therefore always 0.0 minutes.

3. Average fetch time per fetch

The average amount of time spent to fetch a part from the AS/RS is determined by the sum of the fetch time, DELAY-1, DELAY-2 and the normalization delay. The average fetch time of the eight storage areas is 0.09 minutes. DELAY-1 is 0.2 minutes (excluding the normalization delay). The average DELAY-2 for all twenty eight decision rule sets is 0.1972 minutes. The average normalization delay for all decision rule sets is 0.0512 minutes. Therefore, the average total time to fetch a part is 0.5384 minutes (0.09 + 0.2 + 0.1972 + 0.0512). This means that the AS/RS has capability to provide a part to the workcenter cell in every 32.304 seconds (= 0.5384 * 60). This illustrates that the modified model for this research has an AS/RS which operates six times faster than Diesch's original AS/RS design.

4. Time scaling factors for decision rule sets

Table 4-7 shows time scaling factors for twenty eight decision rule sets that have been evaluated in this research. From this Table, it can be seen that rule set RANDOM/FMFS has the minimum time scaling factor value. The rule set S/PT/WINQ has the maximum time scaling factor. In general, the simple rule sets such as RANDOM/RANDOM, RANDOM/FMFS and VALUE/FMFS have larger scaling factors than the complex rule sets such as S/PT/WINQ, SLACK/WINQ and SLACK/NINQ. This means that the simple rule sets in the model operate more quickly than the complex rule sets. The simple rule sets can there-

Table 4-7. Time scaling factor for decision rule sets

| Set | Part selection rules | Machine center selection rule | Minimum scaling factor |
|---|---|---|---|
| 1 | | RANDOM | 12.2067 |
| 2 | RANDOM | FMFS | 12.2913 |
| 3 | | NINQ | 12.0795 |
| 4 | | WINQ | 11.8826 |
| 5 | | RANDOM | 12.0795 |
| 6 | FSFS | FMFS | 12.1607 |
| 7 | | NINQ | 11.9818 |
| 8 | | WINQ | 11.8065 |
| 9 | | RANDOM | 11.8966 |
| 10 | SPT | FMFS | 12.1248 |
| 11 | | NINQ | 11.8468 |
| 12 | | WINQ | 11.6829 |
| 13 | | RANDOM | 11.8576 |
| 14 | DDATE | FMFS | 11.9675 |
| 15 | | NINQ | 11.7589 |
| 16 | | WINQ | 11.6064 |
| 17 | | RANDOM | 11.6784 |
| 18 | SLACK | FMFS | 11.7574 |
| 19 | | NINQ | 11.5990 |
| 20 | | WINQ | 11.6528 |
| 21 | | RANDOM | 11.7927 |
| 22 | S/PT | FMFS | 11.9217 |
| 23 | | NINQ | 11.6739 |
| 24 | | WINQ | 11.4768 |
| 25 | | RANDOM | 12.1102 |
| 26 | VALUE | FMFS | 12.1869 |
| 27 | | NINQ | 11.8951 |
| 28 | | WINQ | 11.7360 |

fore be evaluated in a shorter simulation times. However, it should be noted that real time simulation intervals and other simulation input data are fixed within every decision rule set.

## F. Summary

A time scaling factor for a decision rule set is obtained from the fetch time, route time and delays. This factor is used for adjustment of the model's operation. Also, the scaling factor provides for a meaningful and unbiased comparison between decision rule sets that have been evaluated in this research. To illustrate the use of the scaling factors, the following example is presented.

Example: Suppose,

- Decision rule set 1 is to be simulated for 100 hours of the actual system time.
- Decision rule set 2 is to be simulated for 100 hours of the actual system time.
- The actual processing time for part 1 is 50 minutes.
- Decision rule set 1 has a scaling factor value of 20.
- Decision rule set 2 has a scaling factor value of 16.

These data must be adjusted for the model's operation.

Then,

- Decision rule set 1 is simulated for 5 hours (= 100/20) in the model.
- Decision rule set 2 is simulated for 6.25 hours (= 100/16) in the model.
- The processing time of part 1 is 2.5 minutes (= 50/20) in the decision rule set 1.
- The processing time of part 2 is 3.125 minutes (= 50/16) in the decision rule set 2.

According to the above example, a decision rule set can be compared with the other decision rule sets by using its time scaling factor.

Also, the actual data obtained from the actual system must be adjusted by a time scaling factor of a decision rule set.

In this chapter, the scaling factors for twenty-eight decision rule sets have been presented. The next chapter includes detailed descriptions of twentyeight decision rule sets. Other simulation input information is presented as well.

# V. PHYSICAL SIMULATION

## A. Introduction

As described in Chapter 3, the physical model consisted of two parallel structures: one was the eight storage areas, and the other was the six machine centers. Only one AS/RS cart was used to fetch a part from one of storage areas. Therefore, only one part was selected in every fetch. Whenever the AS/RS cart moved from its starting position to fetch a part, the following three questions were addressed.

- Which part had the highest priority to be selected in the first row of the storage area?
- Which workcenter should process a selected part, one of six machine centers or the turning cell?
- Which machine center should process a selected part if the part was routed to a machine center?

The first decision was made by the part selection rule that was in effect. The second decision was made by the determining first operation of a selected part. Finally, the third decision was made by the machine center selection rule in effect. Both part selection rules and machine center selection rules were extracted from a large set of traditional job shop scheduling rules which could be used for flexible manufacturing systems.

In this research, the selected part selection rules and machine center selection rules were evaluated in a flexible manufacturing environment utilizing the developed FMS physical model. One decision rule set consisted of one part selection rule and one machine center selection rule. Therefore, total number decision rule sets was twenty-eight. The evaluation of seven part selection rules and four machine center selection rules is described in this chapter.

The evaluation work has been completed through physical simulation under the effects of failures of major system components. For the evaluation of the decision rule sets, the following six input parameters were necessary.

- Processing sequence of a part;
- Processing time of a part;
- Due-date of a part;
- Downtime data of major system components;
- Value of a part;
- System simulation time.

To select the best decision rule sets, the following six performance criteria were considered:

- System effectivity (system utilization rate);
- Traveling time of parts;
- Actual production output;
- Manufacturing throughput time;
- Production lateness;
- Work-in-process inventory.

The purpose of this chapter is to describe all of these subjects as they relate to the physical simulation.

## B. Part Selection Rules

### 1. Overview

The physical model had eight identical storage areas. Storage areas 1 to 7 were used for raw materials. Storage area 8 was for semifinished parts. Each storage area contained raw materials for five different parts as shown in Figure 3-6. The front row of the seven storage areas contained seven different parts. Therefore, total number of raw materials in the storage areas was thirty-five. This total was divided into seven different part families. A part family consisted five identical pieces of raw material.

A part selection rule was defined as a decision rule by which the highest priority part was selected from the front row of the storage areas. The rule gave a part a new priority value whenever the AS/RS cart was ready to fetch. One exception was storage area 8. That is, a semi-finished part was independent of a part selection rule. When storage area 8 had a semifinished part, it was always assigned the highest priority value. This rule was also applied in the actual FMS.

Many job shop scheduling rules have been reviewed and summarized in Chapter 2. Of these, some rules can be considered or used as part selection rules without the loss of any general characteristics. Part selection oriented scheduling rules are described in the next section. The final seven part selection rules used in the simulation are described in Section B-3.

## 2. Part selection oriented scheduling rules

Most dispatching rules have been developed for the general job shop. The definition of a dispatching rule for this research was a decision rule used to select a part from storage areas. The dispatching rules were called as part selection rules. Some of the dispatching rules reviewed in Chapter 2 could not be used with the physical FMS model. For example, the rule FASFS (First Arrival at

Shop, First Served) by which a job which arrives at the shop was selected first, could not be used in this research because an initial queue at the front of the shop did not exist in the model.

To choose appropriate part selection rules, the following criteria were used:

- No setup time was necessary in the model;
- The model was a closed-loop system;
- Priority was never changed during the simulation (static rules);
- Each part had a specific (dollar) value, no family of high values or low values;
- No preferred class parts existed in the storage area;
- No truncated version of the SPT rule was considered in part selection.

Table 5-1 shows nineteen part selection rules that satisfy the above criteria. The following notation (5, 6, 7) was used to define various priority rules in Table 5-1.

$t$ = the time at which the selection is made at a storage area;

$i$ = an index of a part ($i$=1, 2, 3, --- 7);

$Z(i,t)$ = a priority value of the $i$ th part at time $t$;

$j$ = an index of operation on a part;

$J$ = a specific value of $j$. The operation for which a part was in the storage area;

$k$ = an index of a storage area's stored parts;

$g(i)$ = the total number of operations on the $i$ th part;

$R(i,j)$ = the time at which the $i$ th part becomes ready for its $j$ th operation - that is, the time at which the $j$-1 th operation is completed;

Table 5-1. Scheduling rules applicable to part selection

| NO. | Rule | Definition | Description |
|---|---|---|---|
| 1 | RANDOM | $Z(i,t)= X(i,J)$ | Part is selected randomly. (note that a part receives a new number for each of its operations). |
| 2 | SPT | $Z(i,t)= P(i,J)$ | Part is selected which has the shortest (imminent) operation processing time. |
| 3 | LPT | $Z(i,t)= -P(i,J)$ | Part is selected which has the longest (imminent) operation processing time. |
| 4 | FOPNR | $Z(i,t)= g(i)-J+1$ | Part is selected which has the fewest operations remaining to be performed. |
| 5 | MOPNR | $Z(i,t)= -(g(i)-J+1)$ | Part is selected which has the most operations remaining to be performed. |
| 6 | LWKR | $Z(i,t)= \sum_{j=J}^{g(i)} P(i,j)$ | Part is selected which has the least work remaining to be performed. |
| 7 | MWKR | $Z(i,t)= -\sum_{j=J}^{g(i)} P(i,j)$ | Part is selected which has the most work remaining to be performed. |
| 8 | TWORK | $Z(i,t)= \sum_{j=1}^{g(i)} P(i,j)$ | Part is selected which has the greatest total work (all operations on the routing). |
| 9 | DDATE | $Z(i,t)= d(i)$ | Part is selected which has the earliest due-date. |
| 10 | SLACK | $Z(i,t)= d(i)-t- \sum_{j=J}^{g(i)} P(i,j)$ | Part is selected which has the least slack time remaining. |
| 11 | OPNDD | $Z(i,t)= R(i,1) + (d(i)-R(i,1))(J/g(i))$ | Part is selected which has the earliest operation due-dates; equally spaced due-dates are assigned to each operation at time part enters the storage area. |

Table 5-1. (continued)

| NO. | Rule | Definition | Description |
|---|---|---|---|
| 12 | S/OPN | $Z(i,t)= \dfrac{d(i)-t-\sum_{j=J}^{g(i)} P(i,j)}{g(i)-J+1}$ | Part is selected which has the smallest ratio of slack-time to number of operations remaining. |
| 13 | S/PT | $Z(i,t)= \dfrac{d(i)-t-\sum_{j=J}^{g(i)} P(i,j)}{\sum_{j=J}^{g(i)} P(i,j)}$ | Part is selected which has the smallest ratio of slack time divided by the remaining processing time. |
| 14 | P+WKR(a) | $Z(i,t)= a * P(i,J) + (1-a)* \sum_{j=J}^{g(i)} P(i,j)$ | Part is selected which has the smallest weighted sum of next processing time and work remaining. |
| 15 | P/WKR(a) | $Z(i,t)= P(i,J) * [\sum_{j=J}^{g(i)} P(i,j)]$ | Part is selected which has the smallest weighted ratio of next processing time to work remaining. |
| 16 | P/TWK | $Z(i,t)= \dfrac{P(i,J)}{\sum_{j=J}^{g(i)} P(i,j)}$ | Part is selected which has the smallest ratio of next processing time to total work. |
| 17 | P+S/OPN(a,b) | $Z(i,t)= a * P(i,J) + (1-a) * (d(i) - t - \sum_{j=J}^{g(i)} P(i,j)) / (g(i)-J+1)^b$ | Part is selected which has the smallest weighted sum of next processing time and slack time per operation remaining. |
| 18 | VALUE | $Z(i,t)= V(i)$ | Part is selected which has the highest dollar value. The priority is taken to be equal to the value of the part. |
| 19 | FSFS | $Z(i,t)= 8-k$ | Part is selected which is stored at the nearest distance from the AS/RS starting point. Storage area 1 has the highest priority. |

P(i,j) = the processing time for the j th operation of the i th part;

X(i,j) = a random number. A particular value of a random variable, uniformly distributed between 0 and 1, assigned to the j th operation of the i th part;

d(i) = the due-date of the i th part;

V(i) = the (dollar) value of the i th part.

In Table 5-1, the rule FSFS (Rule 19) is a rule in which the traveling time of the AS/RS cart was considered. Storage area 1 had the highest priority due to the shortest traveling time. Storage area 7 had the longest traveling time. Storage area 8 was independent of a part selection rule even though the area was the most distant from the cart's starting position.

Conway (5, 6) and Conway et al. (7) determined the best values for Rules 14 (P+ WKR(a)), 15 (P/WKR(a)) and 17 (P+S/OPN(a,b)). These values have been summarized in Chapter 2.

### 3. Part selection rules used in the simulation

Table 5-1 shows nineteen part selection rules which could be evaluated in a flexible manufacturing system environment. Among the nineteen rules, seven part selection rules were finally selected for this research after consideration of the physical model's characteristics.

In a general FMS, a group of parts which has similar characteristics in manufacturing and design is grouped into a part family. Usually, this grouping procedure is accomplished by group technology classification and coding methods (2) which is a manufacturing philosophy. The defined part family usually has a less complicated process sequence when compared to a traditional job shop process route.

In the physical FMS model, seven different families were processed in which maximum number of processing steps of a part was two. This feature was used to select the final seven part selection rules that were evaluated. For example, the rule FOPNR (Rule 4 in Table 5-1) was not expected to show much variation in the model. The rule, therefore, was excluded from further consideration.

Detailed descriptions of the criteria used to select the seven part selection rules are presented below.

- The maximum number of operations for any FMS part was small (two). Parts 1, 3 and 4 needed only two machining operations. Parts 2, 5, 6 and 7 needed one machining operation. Because of this, the rules FOPNR, MOPNR, LWKR, MWKR, OPNDD and S/OPN in Table 5-1 were excluded from further consideration;

- Due to the small number of operations, the TWORK rule was expected to perform like the SPT rule. This rule was also therefore excluded. Since the P/TWK rule was based on the TWORK rule, it was also eliminated;

- The LPT rule never performed better than the SPT rule in earlier studies. This rule was therefore excluded from further consideration;

- All rules in which performance was dependent upon a specific constant were excluded. Those rules included the rules P+WKR(a), P/WKR(a) and P+S/OPN(a,b).

As a result, the following seven part selection rules were selected to be evaluated as part of this research.

- RANDOM rule - A storage area was selected randomly at time of dispatching. The first part of the selected storage area had the highest priority. The first part of each storage area was assigned a new priority value in every fetch.

- FSFS rule - A storage area was selected which was nearest to the AS/RS cart's starting position. The first part in storage area 1 had the highest priority. The first part in storage area 7 had the lowest priority.
- SPT rule - A storage area was selected whose first part that had the shortest operation processing time.
- DDATE rule - A storage area was selected whose first part that had the earliest due-date.
- SLACK rule - A storage area was selected whose first part that had the least slack time remaining. According to the priority equation in Table 5-1, this rule generated a new slack time value for the first part in every fetch.
- S/PT rule - A storage area was selected whose first part that had the smallest ratio of slack time divided by the remaining processing time. According to the priority equation in Table 5-1, this rule generated a new S/PT ratio of the first part in every fetch.
- VALUE rule - A storage area was selected whose first part that had the highest (dollar) value. The priority was taken to be equal to the value of the part.

Each part selection rule was used for the duration of simulation run.

The following operating characteristics applied:

- If no parts were available in the storage areas, the part selection rule in effect ceased operation until at least one part became available;
- Storage area 8 was independent of each part selection rule. Whenever there was a semi-finished part stored on storage area 8, the part was assigned the highest priority in every fetch;
- Whenever a machine center or a turning cell had at least one space for a part, the part selection rule was in effect activated to select the highest priority part;

- If no spaces were available in either machine center cell or the turning cell, the part selection rule in effect ceased operation until at least one space became available;
- Each part selection rule was evaluated under the effects of random failures of major components of the physical model.

## C. Machine Center Selection Rules

### 1. Overview

The physical model had six identical machine centers. Each machine center could process any parts provided from the AS/RS storage areas. A machine center selection rule was defined as a decision rule by which the highest priority machine center was selected to process a part. Each rule assigned a machine center a new priority value when the AS/RS cart was ready to fetch.

Many job shop scheduling rules hav been reviewed and summarized in Chapter 2. Among these, some rules can be used as machine center selection rules without the loss of any general characteristics. Those rules that are machine center selection oriented are described in the next section. The final four machine center selection rules selected for use in the simulation are described in Section C-3.

### 2. Machine center selection oriented scheduling rules

Some traditional job shop scheduling rules can be used as machine center selection rules. The model contained only one turning cell. The process route of a selected part determined which parts were sent to the turning cell.

To select appropriate machine center selection rules for evaluation, the following criteria were used.

- No setup time was necessary in the model;
- A part had only one machining operation on a machine center;
- Each machine center processed a part on a first come-first serve basis (FCFS);
- The priority was never changed during the simulation (static rules);
- No preferred class of machine centers existed in the machine center cell;
- Each machine center had a maximum queue length of five parts;

Table 5-2 shows five machine center selection rules which satisfy the above criteria. The following notation (5, 6) is used to define various priority rules in Table 5-2.

$t$ = the time at which a selection for machine assignment is made. This time is the same as the definition for the part selection rule;

$m$ = an index for a machine center to process the selected parts;

$i$ = an index for a part to be processed by a machine center;

$j$ = an index for an operation of a part;

$J$ = a specific value of $j$, the operation for which a part arrived at a machine center;

$P(i,j)$ = the processing time for the $j$ th operation of the $i$ th part;

$Z'(m,t)$ = the priority value of the $m$ th machine center;

$N(m,t)$ = the total number of parts at the waiting line on the $m$ th machine;

Table 5-2. Scheduling rules applicable to machine center selection

| NO. | Rule | Definition | Description |
|---|---|---|---|
| 1 | RANDOM | Z'(m,t)= X(m) | Machine center is selected randomly at the time a part is fetched. |
| 2 | NINQ | Z'(m,t)= N(m,t) | Machine center is selected which has the shortest queue. |
| 3 | WINQ | Z'(m,t)= Y(m,t) | Machine center is selected which has the least work. |
| 4 | P+WQ(a) | Z'(m,t)= a * P(i,J) + (1-a) * Y(m,t) | Machine center is selected which has the smallest weighted sum of next processing time and work in the waiting line. |
| 5 | FMFS | Z'(m,t)=7-m | Machine center is selected which is nearest to storage areas. Machine center 1 had the highest priority. |

X(m) = a random number, a particular value of a random variable, uniformly distributed between 0 and 1, assigned to the m th machine center;

Y(m,t) = the total work at time t, at the waiting line on the m th machine center (total work was the sum of the imminent operation processing times of the N(m,t) parts in the waiting line).

The FMFS rule (Rule 5) is a rule in which the route time of a part is considered. Machine center 1 had the highest priority, while machine center 6 had the lowest priority. Conway (5, 6) and Conway et al. (7) determined the best parameter values for Rule 4 (P+WQ(a)). These values have been described in Chapter 2.

3. Machine center selection rules used in the simulation

Table 5-2 shows five machine center selection rules which can be evaluated in a flexible manufacturing system environment. Among these five rules, four machine center selection rules were finally selected for evaluation in this research. Rule 4, P+WQ(a) was excluded from the final four rules because its performance was dependent upon a specific constant. As a result, the following four machine center selection rules were selected for evaluation.

- RANDOM rule - A machine center was selected randomly at time a part was fetched.
- FMFS rule - A machine center was selected which was nearest to the AS/RS cell. Machine center 1 had the highest priority while machine center 6 had the lowest priority.
- NINQ rule - A machine center was selected which had the shortest queue at the time a part was fetched.
- WINQ rule - A machine center was selected which had the least work at the time a part was fetched.

The following operating characteristics applied in each simulation run.

- The maximum queue length of each machine center was five parts including the part which being processed. Whenever the queue was full, the machine center was assigned the lowest priority no matter which machine center selection rule was in effect;
- When all machine centers were full with thirty parts (= 5 parts per queue * 6 machine centers), the AS/RS cart stopped fetching parts processed by machine centers. This means that both part selection and machine center selection ceased until a machine center generated one space in its queue. The turning cell selection was independent of a machine center selection rule;

- Each machine center selection rule was evaluated under the effects of random failures of major components of the physcial model.

Seven part selection rules and four machine center selection rules have been described for the physical model. One part selection rule was combined with one machine center selection rule to make one decision rule set. The total number of decision rule sets was twenty-eight. If all nineteen part selection rules and five machine center selection rules had been evaluated, the total number of decision rule set would have been ninety-five. Each decision rule set was simulated for more than 11 hours in the physical model. If all ninety five decision rule sets had been evaluated, the total simulation hours required would have exceeded 1,045 hours (= 95 sets * 11 hours per set). This time requirement was the impetus for limiting the simulation analysis to twenty-eight sets.

## D. Fixed Simulation Parameters

### 1. Overview

Fixed parameters were the operational parameters of the model that remained constant during each of the physical simulations. The fixed parameters of the model were:

- Manufacturing process sequence;
- Processing times of parts;
- Due-dates of parts;
- Maximum queue length of a machine center and the turning cell;
- Values of parts;
- Faliure data for major system components.

This section describes these fixed parameters with respect to the actual system.

2. Manufacturing process sequence

The developed model used seven different part families to represent the seven different part groups manufactured in the actual system. Table 5-3 presents the fixed set of manufacturing process sequences used for the manufactured parts in the model. Parts 1, 3

Table 5-3. Manufacturing process sequences (3)

| Part number | Process sequence |
|---|---|
| 1 | AS/RS, turning cell, AS/RS, machine center, AS/RS |
| 2 | AS/RS, machine center, AS/RS |
| 3 | AS/RS, turning cell, AS/RS, machine center, AS/RS |
| 4 | AS/RS, machine center, AS/RS |
| 5 | AS/RS, turning cell, AS/RS, machine center, AS/RS |
| 6 | AS/RS, machine center, AS/RS |
| 7 | AS/RS, machine center, AS/RS |

and 5 entered to the semi-finished storage area (storage area 8) after passing through the turning cell. Parts 2, 4, 6 and 7 entered to their original storage areas as new raw materials after processing by a machine center.

3. Processing times of machine centers

Actual machining times, in minutes, of seven different part families ranged between 11.2 and 160.4. The turning cell processing times were identical for all parts. Table 5-4 shows the actual machining times and the turning cell processing time for each of the seven part families. Each family contained five identical parts.

The actual machining times and the turning cell processing times were adjusted by a time scaling factor which was described in Chapter 4. Table 4-7 showes time scaling factors for all twenty-eight

Table 5-4. Processing times of part families

| Part number | Actual time (min.) |
|---|---|
| 1 | 47.8 |
| 2 | 82.8 |
| 3 | 23.0 |
| 4 | 11.2 |
| 5 | 14.4 |
| 6 | 160.4 |
| 7 | 20.2 |
| Turning cell | 20.0 |
| Total | 419.8 |

decision rule sets evaluated in this research. Appendix B presents the adjusted processing times with the time scaling factor of each decision rule set.

An example can be used to illustrate the data presented in this Appendix. The reader is referred to the data presented in Appendix B for the RANDOM/RANDOM decision rule set. A scaling factor of 12.2067 applies for this rule. The adjusted processing times are obtained by reducing the original processing times (also presented in Table 5-4) by this factor. All adjusted times total 34.3909 minutes (= 419.8/ 12.2067). This amount is the number of machine-minutes required to produce the seven parts in the model when the RANDOM rule was used for both part selection and machine center selection.

Since the six machine centers and the turning cell can all operate simultaneously, the average production rate was effectively increased by as much as seven. This is equivalent to manufacturing seven parts every 34.3909/7= 4.913 minutes under the RANDOM part selection and RANDOM machine center selection rule. This rate assumes that no breakdowns occur. The material handling system must therefore supply an average of seven parts in 4.913 minutes. As described in Section E of Chapter 4, the average amount of time spent for the AS/RS cart to fetch a part was 0.5384 minutes. This means that the AS/RS cart had sufficient capability to provide 9 parts (= 4.913/0.5384) to either the machine centers or the turning cell.

4. Processing time of the turning cell

The turning cell consisted of lathe 1, lathe 2, a washing station and the robot. The turning cell processing times were identical for all parts (20.0 minutes in the actual system). This total time was divided among lathe 1, lathe 2, the washing station, and the robot. Every part entered to the turning cell was processed by a fixed sequence specified below.

Steps:
1. picking a part up from the input queue by the robot;
2. moving the part to lathe 1 by the robot;
3. processing the part on lathe 1;
4. moving the part to lathe 2 by the robot;
5. processing the part on lathe 2;
6. moving the part to the washing station by the robot;
7. washing the part;
8. moving the part to the finish queue by the robot;
9. the robot's return to the input queue to pick up the next part.

Of these nine steps, steps 1, 2, 4, 6, 8 and 9 were accomplished by the robot. Step 3 was performed on lathe 1, step 5 was completed on lathe 2, and step 7 was performed at the washing station. The total amount of time execute steps 1 through 9 is 20 minutes in the actual system.

The detailed explanation of the turning cell operation has been presented in Chapter 3. An industrial robot in the actual turning cell was represented by a Mini-Mover-5 miniature robot of the model. The Mini-Mover-5 (33) is a 5-axis table-top manipulator which is a point-to-point nonservo arm. Each joint is controlled by a stepper motor mounted on the body. The lifting capacity of the manipulator is 8 ounces when fully extended. The maximum speed is from 2 to 6 inches per second depending upon the weight of the object being handled. The resolution of the manipulator is 0.013 inches which is the smallest amount that the manipulator can move. The arm is connected to a computer (a TRS-80 Model III microcomputer in the model), and the ARMBASIC (33) cassette is loaded. ARMBASIC is a special machine language used to control the Mini-Mover-5. The major structual components of the robot are shown in Figure 5-1.

Speed is a main factor when the Mini-Mover-5 is represents an industrial robot. The Mini-Mover-5 moves at much slower speeds than do full size robotic arms. The Mini-Mover-5 uses the 6 stepper motors to move all joints simultaneously. The speed of each motor (33) is determined by a delay between steps determined by

$$\text{Delay} = 1.2 + 0.03 * D \qquad (5\text{-}1)$$

where D = the delay expression evaluated to an integer.

The smaller the delay, the faster the resulting motion. For a delay value of zero, the arm waits 1.2 milliseconds between motor steps. For each additional unit of delay, the arm waits an additional 0.03 milliseconds between pulses. Comparatively, actual industrial robots have a wide variety of speed values. For example, a G.E. model P50 industrial robot (34) has five joints which are

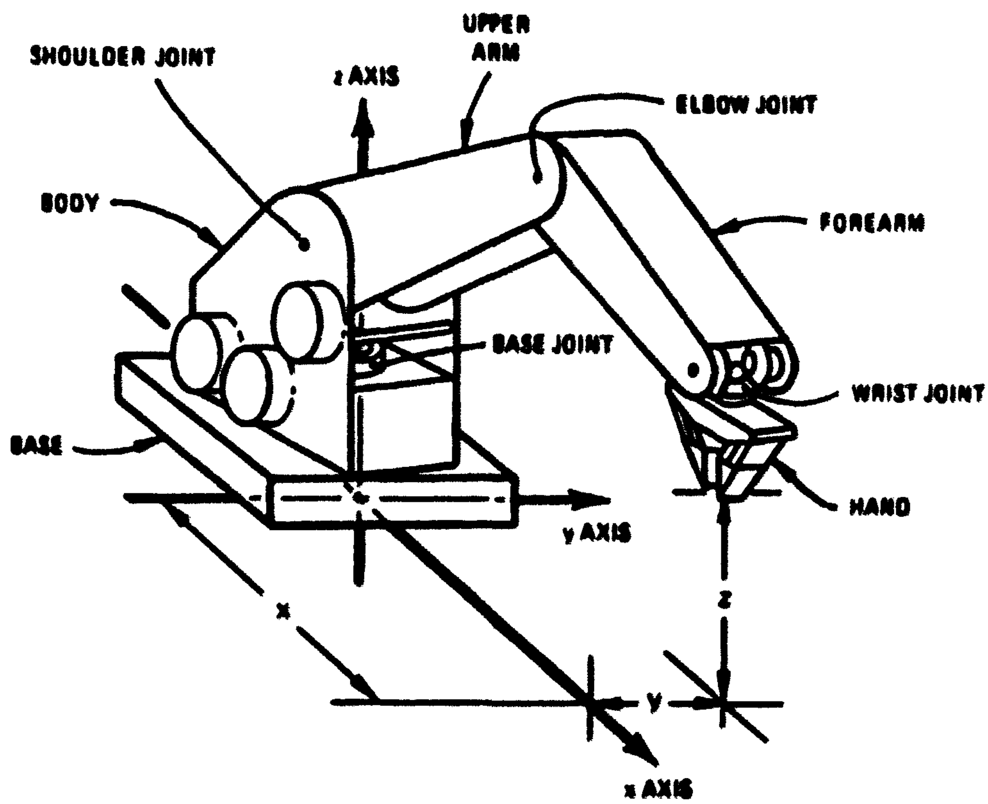



Figure 5-1. Major Structual Components

operated by servo motors. Programmable speeds range between 0.3935 and 78.7 inches per minute.

In both the actual FMS and the model, robots move both horizontally and vertically to load/unload parts. The Mini-Mover-5 in the model operated at 0.7842 minutes per part in the turning cell. This means that the Mini-Mover-5 required 0.7842 minutes in order to complete steps 1, 2, 4, 6, 8 and 9 of the turning cell step sequence. A delay value of 50 in Equation 5-1 was used to obtain this movement speed.

The operation time for the robot in the actual FMS was not available for use in this research. It was assumed that the actual robot's operation time was the same as the Mini-Mover-5 operation time (= 0.7842 minutes/part). This assumption is reasonable because the time programmed on the Mini-Mover-5 is well within the range of speed values of most industrial robots.

To maintain a time 0.7842 minutes per part, the speed of the actual robot would be roughly 20" per second. The robot's operation time was included in the total turning cell time (20 minutes per part). The remaining time was divided between lathe 1, lathe 2 and the washing station. This remaining time was prorated on the basis of data from the actual FMS. Processing times of lathe 1, lathe 2 and the washing station were 56.67%,, 26.67% and 16.66% of the remaining time respectively.

The turning cell time of the actual system is defined in Table 5-5. The actual turning cell processing time was adjusted by a time scaling factor for each decision rule set. It means that the processing times of lathe 1, lathe 2 and the washing station were adjusted by the time scaling factor. However, it should be noted that the robot's operation time (= 0.7842 minutes) was a fixed value in all decision rule sets because the speed of the robot was fixed at a delay of 50. Other component times in the turning cell were consequently adjusted so that the total time was reduced by the value of the applicable scaling factor. Appendix B shows the adjusted processing times of the turning cell under each decision rule set.

Table 5-5. Turning cell time distribution

| Component | Processing time per part (min.) |
|---|---|
| Lathe 1 | 10.8896 |
| Lathe 2 | 5.1249 |
| Washer | 3.2014 |
| Mini-Mover-5 | 0.7842 |
| Total | 20.0000 |

5. Due-dates of parts

Conway (6, 7) has described four different assignment methods for due-dates. Due-dates are the time at which part completion is desired. It was assumed for this research that the due-dates were assigned to parts prior to their being dispatching from storage areas. Further, these dates were assumed to remain constant during the simulation. The four methods of due-date assignment described by Conway are:

- TWK (Total-Work due-dates) - The allowance for flow time (the difference between due-dates and arrival time) was 9 times the sum of the processing times.
- NOP (Number-Of-Operation due-dates) - The allowance for flow time was 8.883 times the number of operations.
- CON (Constant-Allowance due-dates) - Each part received exactly the same allowance (78.7985 minutes).
- RDM (Random-Allowance due-dates) - Each part was assigned an allowance at random. Allowances were uniformly distributed between 0 and 157.597 minutes.

In this research, the TWK due-date assignment method was adopted. Table 5-6 shows the allowance for processing times of seven different part families under the TWK method. The allowances for parts 1, 3 and 5 were computed by including the turning cell time.

Table 5-6. Allowance for flow time

| Part family | TWK (min.) |
|---|---|
| 1 | 610.2 |
| 2 | 745.2 |
| 3 | 387.0 |
| 4 | 100.8 |
| 5 | 309.6 |
| 6 | 1443.6 |
| 7 | 181.8 |

The arrival time of every part was initially assumed to be zero when simulation started. However, every part had its own arrival time value when the part returned to its original storage area as raw material.

The allowances of processing time were also adjusted by a time scaling factor for a decision rule set. The time scaling factors of all twenty-eight decision rule sets are shown in Table 4-7 in Chapter 4. Appendix B shows the adjusted allowances with the time scaling factors for the decision rule sets.

6. Maximum queue length

The number of parts in each storage area was limited to five. Queue length at the machine centers and at the turning cell waiting line was limited to five parts including the part being currently processed.

The performance of a decision rule set was dependent upon maximum queue length. When a machine center was full with five parts, one of the other of machine centers had to have at least one available space for a part to be routed to it. When all machine centers were full, the part selection procedure of a part selection rule was temporarily stopped until a machine center generated a space for a part. When the turning cell was full with five parts, the part selection procedure was also stopped until the turning cell generated a new space for a part. During the physical simulation, these situations occurred both frequently and simultaneously. They are described in greater detail in Chapter 6.

7. Values of parts

The dollar value of a part was necessary to determine a priority in the "VALUE" rule. In this study, actual dollar values of seven different part families were used. Table 5-7 shows the values which were determined from raw material costs and processing costs of parts. The processing cost was a linearly increasing function of the processing time for a part. The processing times of parts 1, 3 and 5 include the turning cell's operation time. The cost function used was ($ 1.333 per unit-minute) * t where t was the processing time in minutes for a part. This value and the raw material costs were based on actual data for parts manufactured in the actual FMS.

Table 5-7. Dollar values of part families

| Part family | Actual processing time (min.) | Processing cost ($/unit) | Raw material cost ($/unit) | Total cost ($/unit) |
|---|---|---|---|---|
| 1 | 67.8 | 90.38 | 100 | 190.38 |
| 2 | 82.8 | 110.37 | 10 | 120.37 |
| 3 | 43.0 | 57.32 | 35 | 92.32 |
| 4 | 11.2 | 14.93 | 3 | 17.93 |
| 5 | 34.4 | 45.86 | 62 | 107.86 |
| 6 | 160.4 | 213.81 | 18 | 231.81 |
| 7 | 20.2 | 26.93 | 56 | 82.93 |

## E. Breakdown Times of Components

### 1. Overview

Twenty-eight decision rule sets were evaluated under the effects of random failures of major system components. There were three major components in the model: the AS/RS cart, the machine centers and the Mini-Mover-5 of the turning cell. These major components were allowed to unpredictably and simultaneously fail during the simulation. These components had different average time intervals between failures (MTBF), different average durations of failures (MDT) and different availabilities. The MTBF is the mean time between failures. MDT is the mean downtime. The availability is defined as the probability that the system is operating at time t (35). In contrast, the reliability is the probability the system has operated with failures over the interval 0 to t. The reliability is always less than the availability. The availability is determined by MTBF/(MTBF + MDT) (35).

Failure data were obtained from the actual system. Detailed failure data analysis by which the MTBF, MDT and availability of each major component were obtained is presented in Appendix C.

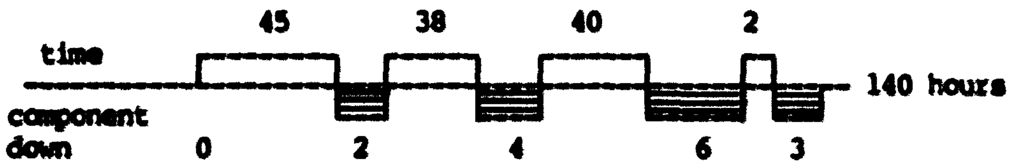
This chapter describes application of the MTBF, MDT and availability of each major component for the model.

### 2. Use of an exponential distribution

The MTBF of each major component was obtained from Appendix C. It can be summarized as follows:

. MTBF of the AS/RS cart = 1.6315 hours;
. MTBF of the robot = 78.6503 hours;
. MTBF of machine center 1 = 66.7697 hours;
. MTBF of machine center 2 = 64.1815 hours;
. MTBF of machine center 3 = 145.2707 hours;
. MTBF of machine center 4 = 183.4626 hours;
. MTBF of machine center 5 = 114.9211 hours;
. MTBF of machine center 6 = 114.9211 hours.

In general, the TBF (time between failures) follows an exponential distribution (35). With an exponential distribution, random numbers which represent uptimes between failures can be generated over simulation run time. A graphical illustration of the failures is shown in Figure 5-2.




$$\text{. MTBF} = \frac{\text{total uptime}}{\text{total number of uptime}} = \frac{45+38+40+2}{4} = 31.25 \text{ (hrs.)}$$

$$\text{. MDT} = \frac{\text{total downtimes}}{\text{total number of downtimes}} = \frac{2+4+6+3}{4} = 3.75 \text{ (hrs.)}$$

$$\text{. Availability} = \frac{\text{total uptime}}{\text{total available production time}} = \frac{125}{140}$$

$$= \frac{\text{MTBF}}{\text{MTBF + MDT}} = \frac{31.25}{31.25 + 3.75} = 0.8929$$

Figure 5-2. Graphical illustration of failures

In Figure 5-2, unshaded areas represent uptimes in which a component is operable. Shaded areas represent downtimes in which a component is in a failed condition.

With an exponential random number generator, unshaded areas (uptimes) can be randomly generated. The random numbers were generated by Equation 5-2 (36).

$$X = \frac{\ln(1 - r)}{- \lambda} \qquad (5\text{-}2)$$

where

X = the desired random observations (uptimes);
r = a random decimal number between 0 and 1;
λ = the MTBF of a component.

Equation 5-2 is an exponential random number generator which is derived from the cumulative distribution function of an exponential distribution. The X values in Equation 5-2 were generated over the simulation run time. The simulation run on a real time basis was 140 hours (= 7 days * 20 hours/day). The run time was adjusted by a time scaling factor for a decision rule set. The adjusted simulation run time is presented in a later section of this chapter.

3. Use of mean downtime (MDT)

The MTBF of each major component was used to randomly generate the uptimes between failures through the exponential random number generator. The MDT of each major component is presented in Appendix C. It can be summarized as follows:

- MDT of the AS/RS cart = 0.1835 hours;
- MDT of the robot = 3.1238 hours;
- MDT of machine center 1 = 6.3225 hours;
- MDT of machine center 2 = 5.7971 hours;
- MDT of machine center 3 = 19.8283 hours;
- MDT of machine center 4 = 3.3628 hours;
- MDT of machine center 5 = 8.8277 hours;
- MDT of machine center 6 = 8.8277 hours.

In general, the DT (downtime) also follows an exponential distribution (35). With an exponential distribution, random numbers which represent downtimes (shaded areas) of failures can be generated. However, the MDT should consist of two time factors to follow an exponential distribution: mean repair time and mean response time. The mean repair time is an average time required to repair electrically or mechanically a failed component. The mean response time is an average time required to administratively manage a failure. The sum (DT) of the mean repair time and the mean response time follows an exponential distribution.

The downtime data collected for the four actual robots contained both the number of failures and their durations. Failure durations included not only repair times, but also times to administratively dispatch repair personnel to the failed unit. This permitted the calculation of a mean downtime (MDT) as shown in Appndix C. Uptimes between failures were generated from an exponential distribution. See Equation 5-2.

Failure data for the actual AS/RS carts again obtained both numbers of failures and their durations. However, the failure durations included only repair times. The mean downtime was again calculated as shown in Appendix C. Uptimes between failures were generated using Equation 5-2.

Failure data were available for only four of the six machine centers. Time intervals and total downtimes were available. No records existed to indicate the number of failures in each interval. A Poisson process was therefore used to estimate the failure rate.

This process is described in Appendix C. Failure rates for the fifth and sixth machine centers were taken as simple averages of the failure rates for machine centers 1 through 4.

The failure durations in the model were not equal to the MDT values obtained for the robot, the AS/RS cart, and the machine centers. The failures that occurred in the model were thus of constant duration for any particular component. This was done because of the vacation in format of the available actual data for each these three FMS subsystems.

4. Failures of the AS/RS cart

A major component of the AS/RS cell was the cart. The cart moved back and forth to dispatch a part selected by a part selection rule. When this cart failed to work either mechanically or electrically, the fetching operations ceased, and no more parts were provided to the workcenters. The failed cart always recovered at its starting position mentioned in Chapter 3.

From Appendix C, the MTBF for the AS/RS cart was 1.6315 hours. The MDT was 0.1835 hours. The availability was 0.8989. Utilizing the MTBF value, random numbers for uptimes between failures were generated from Equation 5-2. However, the MDT was fixed as mentioned previously. During the simulation run time (140 hours), the AS/RS cart failed 60 times. Table 5-8 shows the AS/RS cart's failure data.

The first failure of the cart occurred at a time of 1.2624 hours. This means that no failures occurred between 0 and 1.2624 hours. The first failure recovered at time of 1.4459 (= 1.2624 +

Table 5-8. Failure data for the AS/RS cart

| No. | Random number | Failed at (hr.) | Recovered at (hr.) |
|---|---|---|---|
| 1 | 1.2624 | 1.2624 | 1.4459 |
| 2 | 1.0756 | 2.5215 | 2.7050 |
| 3 | 0.4435 | 3.1485 | 3.3320 |
| 4 | 3.1190 | 6.4510 | 6.6345 |
| 5 | 6.8761 | 13.5106 | 13.6941 |
| 6 | 1.8338 | 15.5279 | 15.7114 |
| 7 | 0.8645 | 16.5759 | 16.7594 |
| 8 | 2.1397 | 18.8991 | 19.0826 |
| 9 | 1.8401 | 20.9227 | 21.1062 |
| 10 | 0.4398 | 21.5460 | 21.7295 |
| 11 | 0.6803 | 22.4098 | 22.5933 |
| 12 | 0.5084 | 23.1017 | 23.2852 |
| 13 | 2.5739 | 25.8591 | 26.0426 |
| 14 | 2.6335 | 28.6761 | 28.8596 |
| 15 | 1.5132 | 30.3728 | 30.5563 |
| 16 | 1.3536 | 31.9099 | 32.0934 |
| 17 | 1.3396 | 33.4330 | 33.6165 |
| 18 | 1.5703 | 35.1868 | 35.3703 |
| 19 | 2.6859 | 38.0562 | 38.2397 |
| 20 | 4.4478 | 42.6875 | 42.8710 |
| 21 | 1.9518 | 44.8228 | 45.0063 |
| 22 | 3.0189 | 48.0251 | 48.2086 |
| 23 | 3.3005 | 51.5091 | 51.6926 |
| 24 | 2.4035 | 54.0961 | 54.2796 |
| 25 | 1.3321 | 55.6117 | 55.7952 |
| 26 | 3.3598 | 59.1550 | 59.3385 |
| 27 | 4.1048 | 63.4433 | 63.6268 |
| 28 | 0.5246 | 64.1514 | 64.3349 |
| 29 | 1.0351 | 65.3700 | 65.5536 |
| 30 | 8.0166 | 73.5702 | 73.7537 |
| 31 | 3.7361 | 77.4898 | 77.6733 |
| 32 | 0.5629 | 78.2361 | 78.4196 |
| 33 | 1.0670 | 79.4867 | 79.6702 |
| 34 | 1.1377 | 80.8079 | 80.9914 |
| 35 | 0.5199 | 81.5113 | 81.6948 |
| 36 | 5.7881 | 87.4829 | 87.6664 |
| 37 | 1.0633 | 88.7298 | 88.9132 |
| 38 | 0.8392 | 89.7524 | 89.9359 |
| 39 | 3.4371 | 93.3730 | 93.5565 |
| 40 | 3.7657 | 97.3222 | 97.5057 |
| 41 | 1.7381 | 99.2438 | 99.4273 |
| 42 | 1.4791 | 100.9064 | 101.0899 |
| 43 | 5.1210 | 106.2109 | 106.3944 |
| 44 | 0.4034 | 106.7978 | 106.9813 |
| 45 | 0.4412 | 107.4225 | 107.6060 |

Table 5-8. (continued)

| No. | Random number | Failed at (hr.) | Recovered at (hr.) |
|---|---|---|---|
| 46 | 1.3554 | 108.9614 | 109.1449 |
| 47 | 2.6253 | 111.7702 | 111.9537 |
| 48 | 2.3639 | 114.3176 | 114.5011 |
| 49 | 1.9030 | 116.4041 | 116.5876 |
| 50 | 1.4097 | 117.9973 | 118.1808 |
| 51 | 2.5975 | 120.7783 | 120.9618 |
| 52 | 1.1128 | 122.0746 | 122.2581 |
| 53 | 1.4294 | 123.6875 | 123.8710 |
| 54 | 0.8666 | 124.7376 | 124.9211 |
| 55 | 1.3286 | 126.2497 | 126.4332 |
| 56 | 2.6451 | 129.0783 | 129.2618 |
| 57 | 1.5269 | 130.7887 | 130.9722 |
| 58 | 0.5535 | 131.5257 | 131.7092 |
| 59 | 2.4265 | 134.1357 | 134.3192 |
| 60 | 4.6921 | 139.0113 | 139.1948 |

0.1835). The next uptime (random number) between the first failure and second failure was 1.0756. Then, the second failure occurred at time of 2.5215 (= 1.4459 + 1.0756). The second failure recovered at time of 2.705 (= 2.5215 + 0.1835). This procedure was continued for the duration of the simulation run time.

5. Failure of the machine center cell

Six machine centers processed parts provided from the AS/RS cell. Each machine center failed randomly during the simulation intervals. More than one machine center could fail simultaneously at any time. When a machine center failed either mechanically or electrically during the processing of a part, the failure was assumed to start as soon as the machine center finished processing. If the machine center was idle, the failure started immediately as described in Chapter 3.

To estimate the mean time between failures and the mean downtime for each of six machine centers, a Poisson process was used. Appendix C shows detailed descriptions of the Poisson process to estimate the MTBF and the MDT for each of six machine centers.

Table 5-9 presents the MTBF, the MDT and the availability for the six machine centers. The MTBF and MDT for machine centers 5 and 6 were the average the MTBF and MDT values for machine centers 1 through 4. As descibed in Appendix C, actual failure data for machine centers 5 and 6 was not available.

Using the MTBF value for each machine center, random numbers for uptimes between failures were generated by Equation 5-2. Table 5-10 shows the failure data used for the simulation. The data are hourly data and were adjusted by a time scaling factor for each decision rule set.

Table 5-9. MTBF, MDT and availability of six machine centers

| Machine center | MTBF (hr.) | MDT (hr.) | Availability |
|---|---|---|---|
| 1 | 66.7697 | 6.3225 | 0.9135 |
| 2 | 64.1815 | 5.7971 | 0.9172 |
| 3 | 145.2707 | 19.8283 | 0.8799 |
| 4 | 183.4626 | 3.3628 | 0.9820 |
| 5 | 114.9211 | 8.8277 | 0.9287 |
| 6 | 114.9211 | 8.8277 | 0.9287 |

. Average MTBF = 114.9211
. Average MDT = 8.8277
. Average Availability = 0.9287

From Table 5-10, total number of failures of the machine center cell is 10 during the simulation interval of 140 hours (real time). For example, first failure of machine center 1 occurred at time of 76.3061. The failure recovered at time of 82.6286 (= 76.3061 +

Table 5-10. Failure data for six machine centers

| Machine center | Failure no. | Random number | Failed at (hr.) | Recovered at (hr.) |
|---|---|---|---|---|
| 1 | 1 | 76.3061 | 76.3061 | 82.6286 |
| | 2 | 6.5257 | 89.1543 | 95.4768 |
| 2 | 1 | 47.5854 | 47.5854 | 53.3825 |
| | 2 | 36.8361 | 90.2187 | 96.0158 |
| 3 | 1 | 99.5060 | 99.5060 | 119.3340 |
| 4 | 1 | 17.3079 | 17.3079 | 20.6707 |
| | 2 | 40.5086 | 61.1793 | 64.5421 |
| 5 | 1 | 65.1861 | 65.1861 | 74.0138 |
| | 2 | 54.0881 | 128.1020 | 136.9300 |
| 6 | 1 | 97.5032 | 97.5032 | 106.3310 |

6.3225). The next uptime between first failure and second failure was 6.5257 hourse. Then, second failure occurred at time of 89.1543 (= 82.6286 + 6.5257). The failure recovered at time of 95.4768 (= 89.1543 + 6.3225). The same procedure was applied for other machine centers.

<u>6. Failures of the turning cell</u>

The turning cell processed the first operation of parts 1, 3 and 5. The cell consisted of lathe 1, lathe 2, a washing station and a miniature robot (the Mini-Mover-5). As described in Chapter 2, the robot picked a part up from the input queue and loaded the part on lathe 1, lathe 2 and the washing station in consecutive operations. Finally, the processed part was placed on the finished queue as a semifinished part by the robot. The robot was idle while the part was processed on either the lathes or the washing station.

In the turning cell, the Mini-Mover-5 was a major component. When the robot failed randomly during the simulation, the entire turning cell was considered to be "down". From actual failure data, the mean time between failures was found to be 78.6511 hours. The mean down time was 3.1238 hours. The availability was 0.9618. These values were obtained from Appendix C.

Utilizing the obtained MTBF value, random numbers for uptimes between failures were generated from Equation 5-2. The MDT was fixed as a constant in each failure. Table 5-11 shows the failure data for the Mini-Mover-5. For example, first failure occurred at time of 9.4556. The failure recovered at time of 12.5794 (= 9.4556 + 3.1238). The next uptime between first failure and second failure was 52.8951. Then, second failure occurred at time of 65.4745 (= 12.5794 + 52.8951). The failure recovered at time of 68.5983 (= 65.4745 + 3.1238). The same procedure was applied for other failures. The data are hourly and was adjusted by a time scaling factor for each decision rule set.

7. Combined failure data

The failures of each cell were addressed separately in the previous sections. Table 5-12 shows the chronological failures of the model which include each of the major system components. The data are in hours and were adjusted by a time scaling factor of each of twenty-eight decision rule sets. Appendix D presents the adjusted failure data in minutes for the twenty-eight decision rule sets.

Table 5-11. Failure data for the Mini-Mover-5

| Failure no. | Random number | Failed at (hr.) | Recovered at (hr.) |
|---|---|---|---|
| 1 | 9.4556 | 9.4556 | 12.5794 |
| 2 | 52.8951 | 65.4745 | 68.5983 |
| 3 | 27.4936 | 96.0919 | 99.2157 |
| 4 | 21.5900 | 120.8060 | 123.9300 |
| 5 | 3.7401 | 127.6700 | 130.7930 |

Table 5-12. Combined chronological failure data

| No. | Failed component | Failed at (hr.) | Recovered at (hr.) |
|---|---|---|---|
| 1 | AS/RS cart | 1.2624 | 1.4459 |
| 2 | AS/RS cart | 2.5215 | 2.7050 |
| 3 | AS/RS cart | 3.1485 | 3.3320 |
| 4 | AS/RS cart | 6.4510 | 6.6345 |
| 5 | Mini-Mover-5 | 9.4556 | 12.5794 |
| 6 | AS/RS cart | 13.5106 | 13.6941 |
| 7 | AS/RS cart | 15.5279 | 15.7114 |
| 8 | AS/RS cart | 16.5760 | 16.7595 |
| 9 | Machine center 4 | 17.3079 | 20.6707 |
| 10 | AS/RS cart | 18.8991 | 19.0826 |
| 11 | AS/RS cart | 20.9227 | 21.1062 |
| 12 | AS/RS cart | 21.5460 | 21.7295 |
| 13 | AS/RS cart | 22.4098 | 22.5933 |
| 14 | AS/RS cart | 23.1017 | 23.2852 |
| 15 | AS/RS cart | 25.8591 | 26.0426 |
| 16 | AS/RS cart | 28.6761 | 28.8596 |
| 17 | AS/RS cart | 30.3728 | 30.5563 |
| 18 | AS/RS cart | 31.9099 | 32.0934 |
| 19 | AS/RS cart | 33.4330 | 33.6165 |
| 20 | AS/RS cart | 35.1868 | 35.3703 |
| 21 | AS/RS cart | 38.0562 | 38.2397 |
| 22 | AS/RS cart | 42.6875 | 42.8710 |
| 23 | AS/RS cart | 44.8228 | 45.0063 |
| 24 | Machine center 2 | 47.5854 | 53.3825 |
| 25 | AS/RS cart | 48.0251 | 48.2086 |
| 26 | AS/RS cart | 51.5091 | 51.6926 |
| 27 | AS/RS cart | 54.0961 | 54.2796 |
| 28 | AS/RS cart | 55.6117 | 55.7952 |
| 29 | AS/RS cart | 59.1550 | 59.3385 |
| 30 | Machine center 4 | 61.1793 | 64.5421 |
| 31 | AS/RS cart | 63.4433 | 63.6268 |

Table 5-12. (continued)

| No. | Failed component | Failed at (hr.) | Recovered at (hr.) |
|---|---|---|---|
| 32 | AS/RS cart | 64.1514 | 64.3349 |
| 33 | Machine center 5 | 65.1861 | 74.0138 |
| 34 | AS/RS cart | 65.3700 | 65.5536 |
| 35 | Mini-Mover-5 | 65.4745 | 68.5983 |
| 36 | AS/RS cart | 73.5702 | 73.7537 |
| 37 | Machine center 1 | 76.3061 | 82.6286 |
| 38 | AS/RS cart | 77.4898 | 77.6733 |
| 39 | AS/RS cart | 78.2361 | 78.4196 |
| 40 | AS/RS cart | 79.4867 | 79.6702 |
| 41 | AS/RS cart | 80.8079 | 80.9914 |
| 42 | AS/RS cart | 81.5113 | 81.6948 |
| 43 | AS/RS cart | 87.4829 | 87.6664 |
| 44 | AS/RS cart | 88.7298 | 88.9132 |
| 45 | Machine center 1 | 89.1543 | 95.4768 |
| 46 | AS/RS cart | 89.7524 | 89.9359 |
| 47 | Machine center 2 | 90.2187 | 96.0158 |
| 48 | AS/RS cart | 93.3730 | 93.5565 |
| 49 | Mini-Mover-5 | 96.0919 | 99.2157 |
| 50 | AS/RS cart | 97.3222 | 97.5057 |
| 51 | Machine center 6 | 97.5032 | 106.3310 |
| 52 | AS/RS cart | 99.2438 | 99.4273 |
| 53 | Machine center 3 | 99.5060 | 119.3340 |
| 54 | AS/RS cart | 100.9060 | 101.0900 |
| 55 | AS/RS cart | 106.2110 | 106.3940 |
| 56 | AS/RS cart | 106.7980 | 106.9810 |
| 57 | AS/RS cart | 107.4230 | 107.6060 |
| 58 | AS/RS cart | 108.9610 | 109.1450 |
| 59 | AS/RS cart | 111.7700 | 111.9540 |
| 60 | AS/RS cart | 114.3180 | 114.5010 |
| 61 | AS/RS cart | 116.4040 | 116.5880 |
| 62 | AS/RS cart | 117.9970 | 118.1810 |
| 63 | AS/RS cart | 120.7780 | 120.9620 |
| 64 | Mini-Mover-5 | 120.8060 | 123.9300 |
| 65 | AS/RS cart | 122.0740 | 122.2580 |
| 66 | AS/RS cart | 123.6870 | 123.8710 |
| 67 | AS/RS cart | 124.7380 | 124.9210 |
| 68 | AS/RS cart | 126.2500 | 126.4330 |
| 69 | Mini-Mover-5 | 127.6700 | 130.7930 |
| 70 | Machine center 5 | 128.1020 | 136.9300 |
| 71 | AS/RS cart | 129.0780 | 129.2620 |
| 72 | AS/RS cart | 130.7890 | 130.9720 |
| 73 | AS/RS cart | 131.5260 | 131.7090 |
| 74 | AS/RS cart | 134.1360 | 134.3190 |
| 75 | AS/RS cart | 139.0110 | 139.1950 |

8. Theoretical system effectivity

In this research, theoretical system effectivity was defined as the maximum system utilization rate which was achieved by the model during the simulation with consideration of failures. The data in Tables 5-8, 5-10 and 5-11 indicate the following:

- The AS/RS cart failed 60 times and was down a total of 11.01 hours (0.1835 hours * 60 times) in each simulation run;
- The machine center cell failed 10 times and was down a total of 77.2762 hours (6.3225 * 2 + 5.7971 * 2 + 19.8283 + 3.3628 * 2 + 8.8277 * 2 + 8.8277) in each simulation run;
- The Mini-Mover-5 failed 5 times and was down a total of 15.619 hours (3.1238 hours * 5 times) in each simulation run.

The MDT was constant in each failure. Then, the total failure time was 103.9052 hours (11.01 + 77.2762 + 15.619) in the model.

The theoretical system effectivity is defined by the expression below.

$$TSE = 1 - \frac{TFT}{M * CAP} \tag{5-3}$$

where

TSE = the theoretical system effectivity;
CAP = the total simulation time available at full production;
M = the total number of cells including the AS/RS cell, the machine center cell and the turning cell. (M= 3);
TFT = the total failure time.

The total simulation time was 140 hours in any simulation run. Then, from Equation 5-3,

$$TSE = 1 - \frac{103.9052}{3 * 140} = 0.7526$$

According to Equation 5-3, the theoretical system effectivity is 1 without failures. With the failures of all three major components, the system can achieve a maximum utilization rate of 75.26%.

Each decision rule set generated an actual system effectivity which was less than the theoretical system effectivity value. The actual system effectivities are described in a later section.

## F. General Assumptions in Comparing Decision Rule Sets

For consistant comparisons of decision rule sets, the following assmptions were adopted.

- The part processing times were known and were sequence independent;
- The due-dates were known;
- Once a part was started on a model, it was processed to completion;
- There were no merging or assembly operations;
- Only one part could be processed on a workcenter at a given time;
- There was no alternative routing;
- There was no preemption;
- Lot splitting and phase lapping were not permitted.

## G. Performance Criteria

### 1. Overview

All combinations of seven part selection rules and four machine center selection rules were evaluated in this research. Decision rule sets were evaluated using the six performance criteria below.

- Actual system effectivity (system utilization rate);
- Travelling time of parts;
- Actual production output;
- Manufacturing throughput time;
- Work-in-process inventory;
- Production lateness.

Each performance criterion was affected by random failures and the idle times of major components in the model. The performance criteria are individually described in the following sections.

## 2. Actual system effectivity (system utilization rate)

The theoretical system effectivity in section E was defined as the maximum effectivity that the model could achieve under the effects of failures. In contrast, the actual system effectivity is defined as the ratio of the actual operation time required to produce parts divided by the available manufacturing time. This actual time does not include the failure times and idle times of system components. The actual operation time of the model includes the following three major factors:

- Model fetch time - This time factor is described in Chapter 4. A model fetch time from each of eight storage areas is an average time value. However, observed fetch time values from each storage area are used to obtain the actual system effectivity. Any failure time and idle time of the AS/RS cart are excluded from the model fetch time;

- Processing times on the machine center cell - The processing time of each part family is presented in Table 5-4. This time does not include any failure time and idle time of the machine center cell. However, the time is scaled down by a time scaling factor for each decision rule set;

- Processing times on the turning cell - The processing time of the turning cell is presented in Table 5-5. The turning cell operation time of a part is 20 minutes in real time. Failure time and idle time are not included in the turning cell operation time. However, the time is scaled down by a time scaling factor for each decision rule set.

The throughput time of a part (described in a later section) reflects both factors, failure times and idle times, in the performance of each decision rule set.

As described, the failure times of the three major system components are fixed in each decision rule set. This means that lower than average actual system effectivity indicates high idle times in a decision rule set.

The actual system effectivity is defined by Equations 5-4 through 5-6.

$$EFFs(i) = 1 - \frac{TFT + TIT(i)}{M * CAP} \qquad (5\text{-}4)$$

$$= EFF_{AT}(i) + EFF_{MC}(i) + EFF_{TC}(i) \qquad (5\text{-}5)$$

$$= \frac{\sum_{l=1}^{N_1(i)} AT(l) + \left(\sum_{k=1}^{6}\sum_{j=1}^{N_1(i)} PT(k,j)\right)/6 + \sum_{j=1}^{N_2(i)} TC(j)}{M * CAP} \qquad (5\text{-}6)$$

where

$EFFs(i)$ = actual system effectivity of decision rule set i;
$EFF_{AT}(i)$ = actual AS/RS cart effectivity of decision rule set i;
$EFF_{MC}(i)$ = actual machine center cell effectivity of decision rule set i;
$EFF_{TC}(i)$ = actual turning cell effectivity of decision rule set;
TFT = total failure times (min.);
TIT(i) = total idle times of decision rule set i (min.);
CAP = the available manufacturing time (min.). This time was equal to the total simulation time;

| | | |
|---|---|---|
| M | = | the total number of cells: the AS/RS cell, the machine center cell and the turning cell (M= 3); |
| AT(l) | = | the amount of travelling time of the AS/RS cart from/to storage area l; |
| PT(k,j) | = | the amount of processing time for part j in machine center k; |
| TC(j) | = | the amount of turning cell operation time for part j; |
| $N_1(i)$ | = | total number of fetches from the AS/RS cell of decision rule set i; |
| $N_k(i)$ | = | total number of parts processed by machine center k under decision rule set i; |
| $N_2(i)$ | = | total number of parts processed by the turning cell under decision rule set i; |

i = an index for a decision rule set (i=1, 2,---, 28);
j = an index for a part (j=1, 2, ---, $N_1(i)$ or $N_k(i)$ or $N_2(i)$);
k = an index for a machine center (k=1, 2, ---, 6);
l = an index for a storage area (l=1, 2, ---, 8).

In Equation 5-6, the numerator represents the amount of running times of three major cells. The amount of running time is less than the total amount of available manufacturing time (the denominator of Equation 5-6)

The individual effectivity of each of the three major cells was computed as follows.

<u>a. Actual effectivity of the AS/RS</u> The effectivity of the AS/RS cell is defined as the effectivity of the AS/RS cart.

The effectivity of the cart is represented by

$$EFF_{AS}(i) = \frac{\sum_{j=1}^{N_1(i)} AT(l)}{CAP} \qquad (5\text{-}7)$$

where

| | | |
|---|---|---|
| $EFF_{AS}$ (i) | = | the actual effectivity of the AS/RS cell under decision rule set i; |
| CAP | = | the available simulation time; |

$N_t(i)$ = total number of fetches from the AS/RS cell under a decision rule set i;
AT(l) = the net amount of travelling time of the AS/RS cart from/to a storage area l;

i = an index for a decision rule set (i=1, 2, ---, 28);
l = an index for a storage area (l=1, 2, ---, 8).

b. Actual effectivity of the machine center cell The actual effectivity of the machine center cell is defined as the average effectivity of six machine centers.

The effectivity of the machine center cell is defined by

$$EFF_{MC}(i) = \frac{\sum_{k=1}^{6}\sum_{j=1}^{M(k)} PT(k,j)}{6 * CAP} \tag{5-8}$$

where

$EFF_{MC}(i)$ = the actual effectivity of the machine center cell under decision rule set i;
CAP = the available manufacturing time (the total simulation time);
PT(k,j) = the amount of processing time for required by part j on machine center k;
M(k) = total number of parts processed by machine center k;

i = an index for a decision rule set (i=1, 2, ---, 28);
j = an index for a part (j=1, 2, ---, M(k));
k = an index for a machine center (k=1, 2, ---, 6).

c. Actual effectivity of the turning cell The actual effectivity of the turning cell is defined as the total effectivity of lathe 1, lathe 2, the washing station and the Mini-Mover-5. A part was sequentially processed by lathe 1, lathe 2 and the washing station. If the Mini-Mover-5 was idle due to either a failure or no parts in the turning cell input queue, the entire turning cell was idle. The Mini-Mover-5 waited at the front of each lathe or the washing station when lathe 1, lathe 2 and the washing station were in operation.

The effectivity of the turning cell was defined by

$$EFF_{TC}(i) = \frac{\sum_{j=1}^{N2} PT_1(j) + \sum_{j=1}^{N2} PT_2(j) + \sum_{j=1}^{N2} PT_W(j) + \sum_{j=1}^{N2} PT_R(j)}{CAP} \quad (5\text{-}9)$$

where

$EFF_{TC}(i)$ = the actual effectivity of the turning cell under decision rule set i;
CAP = the available manufacturing time (the total simulation time);
$PT_1(j)$ = the processing time of lathe 1 for part j;
$PT_2(j)$ = the processing time of lathe 2 for part j;
$PT_W(j)$ = the washing time for part j;
$PT_R(j)$ = the net Mini-Mover-5 operating time for a part j;
$N_2$ = total number of parts processed by the turning cell;

i = an index for a decision rule set (i=1, 2, ---, 28);
j = an index for a part (j=1, 2, ---, $N_2$).

By comparison of the actual system effectivity with the theoretical system effectivity mentioned in section E, an additional criterion called by Relative System Effectivity was considered and used to evaluate decision rule sets. The relative system effectivity is defined by the expression below.

$$RSE(i) = \frac{EFF_S(i)}{TSE} \quad (5\text{-}10)$$

where

RSE(i) = the relative system effectivity of decision rule set i;
TSE = the theoretical system effectivity (= 0.7526);
$EFF_S$ (i) = the actual system effectivity of decision rule set i;
i = an index for a decision rule set (i=1, 2, --- , 28).

3. Total traveling time of parts

In a decision rule set, the total traveling of parts is defined as the sum of the amount of fetch time for a part from each of eight storage areas and the amount of routing time to either one of six machine centers or the turning cell. This means that the total traveling time is determined by the sum of model fetch time and model route time. This criterion was affected by both the distance from a storage area and routing distance to a workcenter during the available production time (CAP). The criterion is described by Equation 5-11.

$$TTP(i) = \sum_{j=1}^{N_f(i)} FT(j) + \sum_{j=1}^{N_f(i)} RT(j) \qquad (5\text{-}11)$$

where

TTP(i) = the total travelling time of decision rule set i;
FT(j) = the fetch time for part j;
RT(j) = the route time for part j;
$N_f$(i) = the total number of fetches from the AS/RS cell under decision rule set i;

i = an index for a decision rule set (i=1, 2, ---, 28);
j = an index for a part (j=1, 2, ---, $N_f$(i)).

4. Actual production output

The actual production output is defined as an actual number of parts produced by the machine center cell and the turning cell under a decision rule set. In the model, the production output was dependent upon three factors.

. The AS/RS fetching capacity;
. The machine center cell capacity and the turning cell capacity;
. The failures of major components.

The AS/RS fetching capacity was the capacity to provide parts to either the machine center cell or the turning cell. Both the machine center cell capacity and the turning cell capacity were the capacity to produce parts. The failures of major components were fixed in every decision rule set.

If the AS/RS fetching capacity was larger than the capacities of the machine center cell or the turning cell, the actual production output would be dependent upon the capacity of the machine center or the turning cell. If the capacity of the machine center or the turning cell was larger than that of the AS/RS, the actual production output would be dependent upon the capacity of the AS/RS.

In this research, the AS/RS fetching capacity was 1.8574 parts per minute as mentioned in Chapter 4. The average fetch time to fetch a part was 0.5384 minutes in all twenty-eight decision rule sets. This capacity was an average value for all decision rule sets. The capacities of the machine center cell and the turning cell were determined by the total processing time (Table 5-4) and the average time scaling factor (Table 4-7 in Chapter 4). The total processing time required to produce seven parts was 419.8 minutes in the actual system. This value was adjusted by an average time scaling factor of the physical model.

The average time scaling factor of all decision rule sets was 11.8825. Then, the total processing time for the model became 35.3293 minutes (= 419.8/ 11.8825). Since the six machine centers and the turning cell operated simultaneously, the average production rate was effectively increased by seven. This was equivalent to manufacturing seven parts every 35.3293/7 = 5.047 minutes. Then, the capacities of the machine center cell and the turning cell were 1.387 parts per minute.

This indicates that the AS/RS cell had enough capability to provide parts to the machine center cell and the turning cell. However, the AS/RS cell fetching capacity was limited by by two factors. One was the failures of major components, the other was the maximum queue length of each machine center and the turning cell.

If several breakdowns occurred in the AS/RS cart during the simulation, the fetch time increased. This decreased the AS/RS fetching capacity. If all the waiting lines on the machine centers and the turning cell input queue were full, the fetching capacity was also reduced because the AS/RS cell was idle.

The actual production output was compared with the total number of fetches under each decision rule set. Every decision rule set generated different values of the actual production output and total numbers of fetches. The total number of fetches was dependent upon the storage areas selected, the DELAY-2 mentioned in Chapter 4 and the failures of the AS/RS cart. The DELAY-2 time was necessary in order to update the current operating status of the model under a specific decision rule set.

A parameter defined as an achievement rate is described by the expression below.

$$AR(i) = \frac{ND(i)}{NF(i)} \tag{5-12}$$

where

$AR(i)$ = the achievement rate of decision rule set i;
$ND(i)$ = the actual production output of decision rule set i;
$NF(i)$ = total number of fetches under decision rule set i;
i = an index for a decision rule set (i=1, 2, ---, 28);

5. Total manufacturing throughput time

This criterion is defined as total manufacturing time of all processed parts during the simulation. The average throughput time is defined as follows.

$$\bar{F}(i) = \frac{\sum_{j=1}^{ND(i)} F(j)}{ND(i)} = \frac{\sum_{j=1}^{ND(i)} (PT(j) + W(j))}{ND(i)} = \frac{\sum_{j=1}^{ND(i)} (C(j) - r(j))}{ND(i)} \tag{5-13}$$

where

$\bar{F}(i)$ = the average throughput time under decision rule set i;
$F(j)$ = the manufacturing throughput time of part j;
$ND(i)$ = the actual production output under decision rule set i;
$PT(j)$ = the processing time of part j;
$W(j)$ = the sum of idle times and failure times that a part has experienced until its release by either a machine center or the turning cell;

C(j) = the completion time of part j;
r(j) = the arrival time of part j to a storage area as raw material;

i = an index for a decision rule set (i=1, 2, ---, 28);
j = an index for a part (j=1, 2, ---, ND(i)).

The numerators of Equation 5-13 represent the total manufacturing throughput time. According to Equation 5-13, the average throughput time is affected by the idle times of parts. If W(j) is increased, the average throughput time would be also increased. Such an increase would correspond to a reduced level of actual production output.

6. Work-in-process inventory

In this research, the work-in-process inventory is defined as the total processing times of parts waiting to be processed by a machine center or the turning cell. There are two ways (5) to measure the work-in-process inventory at the end of the simulation for a decision rule set.

a. Work Remaining. The sum of the processing times of all operations not yet completed or in process for all parts in the machine center cell or the turning cell.

b. Imminent Operation Work Content. The sum of the processing times of the particular operations for which parts were waiting in each queue of six machine centers or the turning cell input queue.

In addition, Conway (5) has described two more measurements including Total Work Content and Work Completed. Total work content is the sum of the processing times of all operations of all parts in the model. Work completed is the sum of the processing times of all completed operations of all parts in the model. The total work content is not meaningful in this research because the model always processed thirty-five parts in every decision rule set. The work completed was indirectly represented by the actual production output mentioned earlier.

Total waiting time was added to measure the work-in-process inventory. The total waiting time was defined as total waiting times on the waiting lines of the machine center cell. Even though this factor (W(j) in Equation 5-13) was included in the total throughput time, it was extracted from the throughput time for the detailed analysis. In the case of parts to be processed by the turning cell, the total waiting time of parts cannot be computed because the CBM computer does not know when the robot picks up each of parts on the turning cell input queue. As mentioned previously, the robot was controlled by the TRS-80 computer which did not have a communication link with the CBM computer.

The average waiting time is described by the expression below.

$$WT(i) = \frac{\sum_{j=1}^{ND(i)} WT(j)}{ND(i)} = \frac{\sum_{k=1}^{6}\sum_{j=1}^{N(k)} (S(k,j) - A(k,j))}{ND(i)} \qquad (5\text{-}14)$$

where

WT(i) = the average waiting time on the machine center cell under decision rule set i;
WT(j) = the waiting time of part j;
ND(i) = the actual production output under decision rule set i;
S(k,j) = machine starting time for part j on machine center k;

A(k,j) = the arrival time of part j to machine center k;
$N_3(k)$ = total number of parts processed by machine center k;

j = an index for a part (i=1, 2, ---, $N_3(k)$);
k = an index for a machine center (j=1, 2, ---, 6).

## 7. Total production lateness

The total production lateness is defined as the sum of differences between the actual time at which a part was completed and the time at which completion was desired (due-date) under a decision rule set. The average production latenese is the average value of lateness of all processed parts. The average lateness is defined as follows.

$$\overline{LD}(i) = \frac{\sum_{j=1}^{ND(i)} (C(j) - d(j))}{ND(i)} \qquad (5\text{-}15)$$

$$= \frac{\sum_{j=1}^{ND(i)} (r(j) + W(j) + PT(j) - d(j))}{ND(i)}$$

where

$\overline{LD}(i)$ = the average production lateness of decision rule set i;
C(j) = the completion time of part j;
d(j) = the due-date of part j;
ND(i) = the actual production output under decision rule set i;
r(j) = the arrival time of part j to storage area as raw material;
W(j) = the sum of idle time and failure time that a part has experienced until a machine center or the turning cell releases it;
PT(j) = the processing time of part j;

i = an index for a decision rule set (i=1, 2, ---, 28);
j = an index for a part (j=1, 2, ---, ND(i)).

The arrival time, r(j) in Equation 5-15 represents the start of the production process for parts that re-enter the model as raw material. At the beginning of the simulation, all r(j) values are initially zero. A part is assigned a new r(j) value each time it completes the production process and re-enters the storage area as raw material.

## H. System Simulation Times

In this study, seven part selection rules and four machine center selection rules were evaluated. One part selection rule was combined with a machine center selection rule. The total number of decision rule sets was twenty-eight. These rules have been described in Sections B and C of this chapter.

To evaluate the full performance of a decision rule set, each set was simulated for 140 hours of actual system time. This amount of time was equivalent to one-week period time (7 days per week at 20 hours per day). The total simulation time was 3,920 hours (= 28 decision rule sets * 140 hours per a decision rule set).

Each decision rule set had its own time scaling factor as described in Chapter 4. The actual simulation time was adjusted by a time scaling factor for the physical simulation of the model. Table 5-13 shows each specific simulation time determined by the time scaling factor used with each of the twenty-eight decision rule sets.

## I. Summary

This chapter has described seven part selection rules and four machine center selection rules. Each decision rule set was simulated with four fixed simulation parameters such as manufacturing sequence, process times, due-dates and values of parts. The model processed seven part families which were classified for the FMS operations. Three major FMS components were allowed to fail unpredictably and simultaneously during each simulation run. The failure of the major components were estimated from the actual failure data. All actual data for the physical simulation was scaled down by a specific time scaling factor for each decision rule set.

The best decision rule sets for the FMS model were determined using six major performance criteria. Each performance criterion was heavily dependent upon the idle times of major components of the model. The performance of each decision rule set was plotted on a time axis to observe the chronological changes under the effects of the failures and the idle times.

Finally, the simulation time for every decision rule set is shown in Table 5-13. Each simulation time was equivalent to 140 hours in the actual system.

Extensive control software implements the simulation characteristics which have been described in this chapter. This software is the subject of the following chapter.

Table 5-13. Simulation times for decision rule sets (minutes)

| No. | Decision rule set | Time scaling factor | Simulation time |
|---|---|---|---|
| 1 | RANDOM/RANDOM | 12.2067 | 688.1467 |
| 2 | RANDOM/FMFS | 12.2813 | 683.4102 |
| 3 | RANDOM/NINQ | 12.0795 | 695.3930 |
| 4 | RANDOM/WINQ | 11.8826 | 706.9160 |
| 5 | FSFS/RANDOM | 12.0795 | 695.3930 |
| 6 | FSFS/FMFS | 12.1607 | 690.7497 |
| 7 | FSFS/NINQ | 11.9818 | 701.0633 |
| 8 | FSFS/WINQ | 11.8065 | 711.4725 |
| 9 | SPT/RANDOM | 11.8966 | 706.0841 |
| 10 | SPT/FMFS | 12.1248 | 692.7949 |
| 11 | SPT/NINQ | 11.8468 | 709.0522 |
| 12 | SPT/WINQ | 11.6829 | 718.9996 |
| 13 | DDATE/RANDOM | 11.8576 | 708.4064 |
| 14 | DDATE/FMFS | 11.9675 | 701.9010 |
| 15 | DDATE/NINQ | 11.7589 | 714.3525 |
| 16 | DDATA/WINQ | 11.6064 | 723.7386 |
| 17 | SLACK/RANDOM | 11.6784 | 719.2766 |
| 18 | SLACK/FMFS | 11.7574 | 714.4437 |
| 19 | SLACK/NINQ | 11.5990 | 724.2004 |
| 20 | SLACK/WINQ | 11.6528 | 720.8568 |
| 21 | S/PT/RANDOM | 11.7927 | 712.3051 |
| 22 | S/PT/FMFS | 11.9217 | 704.5975 |
| 23 | S/PT/NINQ | 11.6739 | 719.5539 |
| 24 | S/PT/WINQ | 11.4768 | 731.9113 |
| 25 | VALUE/RANDOM | 12.1102 | 693.6302 |
| 26 | VALUE/FMFS | 12.1869 | 689.2647 |
| 27 | VALUE/NINQ | 11.8951 | 706.1731 |
| 28 | VALUE/WINQ | 11.7360 | 715.7464 |

# VI. MODEL CONTROL SOFTWARE

## A. Introduction

The physical model control system consisted of two parts: electrical control and software control. Electrical control is defined as the control of physical components (electronic and electrical devices) of the control system. Software control is defined as the control of the entire set of programs, procedures, and related documentation. In this chapter, the software control of the model is described. Electrical control was not a part of this research. Diesch (3) has described the electrical control of the model in detail.

The software control consisted two distinct parts. The software used to control the robot is presented first. This is followed by a description of the software used to control the rest of the model.

The control software for the robot was identical in each of twenty-eight decision rule sets. The only difference in each rule set was the input data such as the processing times of lathe 1, lathe 2, the washer and the simulation run time. The control software for the rest of the model consisted of the following subroutines:

- . Part selection procedure;
- . Machine center selection procedure;
- . Fetching procedure;
- . Routing procedure;
- . Machine center processing procedure;
- . Retrieval procedure;
- . Failure checking procedure.

There were twenty-eight control software programs which contained the above subroutines. Each subroutine is seperately described in this chapter.

## B. Robot Control Software

### 1. Overview

As mentioned previously, the robot (the Mini-Mover-5) was controlled by a Radio Shack TRS-80 microcomputer. The foundation of the robot software control was a machine language program called ARMBASIC (33). The ARMBASIC program enabled the TRS-80 and the robot to communicate with a straightforward set of commands. The robot is constructed with six DC stepper motors to control each of the five axes of movement. Through the use of ARMBASIC, simple commands instruct each of the six stepper motors the TRS-80 to move a particular number of steps.

### 2. Program commands

The ARMBASIC has five major commands (33). They are described in the following sections.

a. @STEP command The syntax for this command is as follows:

@STEP D, J1, J2, J3, J4, J5, J6

where:

D = an integer for the delay between the pulses to the six stepper motors;
J1 = an integer for the number of steps of base swivel;
J2 = an integer for the number of steps of shoulder bend;
J3 = an integer for the number of steps of elbow bend;

J4 = an integer for the number of steps of the right wrist;
J5 = an integer for the number of steps of the left wrist;
J6 = an integer for the number of steps of the hand.

This commands causes all of the six motors to move simultaneously. The joint expressions, J1 - J6, evaluated as integers, determine the motion of each joint. After evaluation, the sign of each expression indicates the direction in which each motor should be driven.

b. @SET command   The syntax for this command is as follows:

@SET D

This command puts the manipulator into a "manual" mode. By pressing certain keys on the TRS-80 keyboard, each joint of the manip- ulator can be moved. The optional delay expression D determines the speed of motion.

c. @CLOSE command   The syntax for this command is as follow:

@CLOSE D

This command causes the hand to close until the grip switch indicates that a gripping force has been reached. This occurs either when the fingers close on an object, or when the fingers close and touch one another. The optional delay expression D determines the speed of closure.

d. @RESET command   The syntax for this command is as follows:

@RESET

This command resets the counters for the six motors J1 - J6 to zero. This command is used for arm intialization.

e. @READ command The syntax for this command is as follows:

@READ V1, V2, V3, V4, V5, V6

where:

V1 - V6 = optional BASIC variables.

This command reads the number of steps that the robot has moved on each motor. Thus, the current position of the manipulator is available to the user's basic program at any time.

3. Operation of control program

The remainder of the robot control software was written in BASIC. The ARMBASIC program allowed the use of robot control commands within a BASIC program.

The robot control program consisted of the following:

- Moving the robot to a specified point;
- Determining failure occurrence times and recovery times of the robot;
- Determining the presence of a part at the turning cell input queue;
- Entering the cycle times of lathe 1, lathe 2, and the washer;
- Entering the simulation run time of a decision rule set;
- Computing the simulation statistics of the turning cell.

The majority of the program was dedicated to the movement of the robot and the execution of the robot's failures. Whenever the robot was instructed to move a particular number of steps, a failure checking procedure was performed. When a failure occurred at a specified time, normal movement of the robot ceased until the failure recovered.

A real time clock was programmed to determine the following time factors:

- When should each of lathes and washer complete their processes?
- When should the robot fail?
- When should the failed robot recover?
- How long should each of lathes and washer continue their processes after the failed robot recovered? This question arose because both lathes and washer were "down" when the robot failed;
- What was the turning cell effectivity at a specific time?
- When should each simulation run be completed?

The cycle times and the simulation run time were adjusted time values which were scaled down by a time scaling factor for each decision rule set. Appendix B shows both the cycle times and the simulation run time of each decision rule set.

A flow chart of the robot software is shown in Figure 6-1a and Figure 6-1b. A complete program listing for the RANDOM/RANDOM decision rule set is presented in Appendix E. A list of variables used in the robot control program is shown in Table 6-1. The program was written in a subroutine format with a main program to coordinate the subroutines. The subroutines are shown in Table 6-2.

<u>4. Robot move sequence</u>

The moves associated with the robot to execute the desired operation of the turning cell are shown in Figure 6-2. The locating block was used as a zero reference point at the beginning of each simulation. From this point, the robot was instructed to move to the 27 different locations. The robot moved in the straightest possible path between two points. Therefore, it was necessary to program some

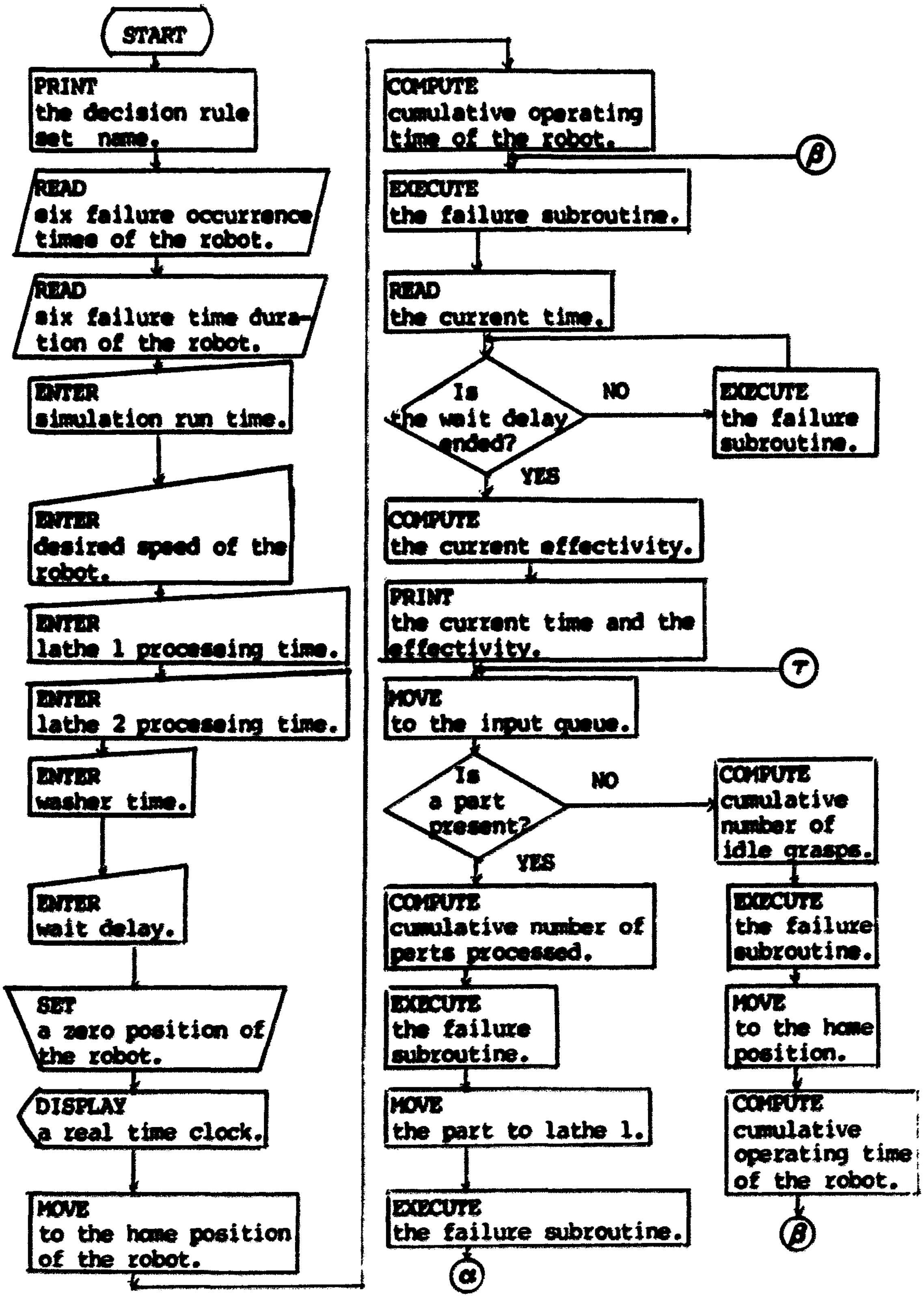



Figure 6-1a. Flow chart of robot control software

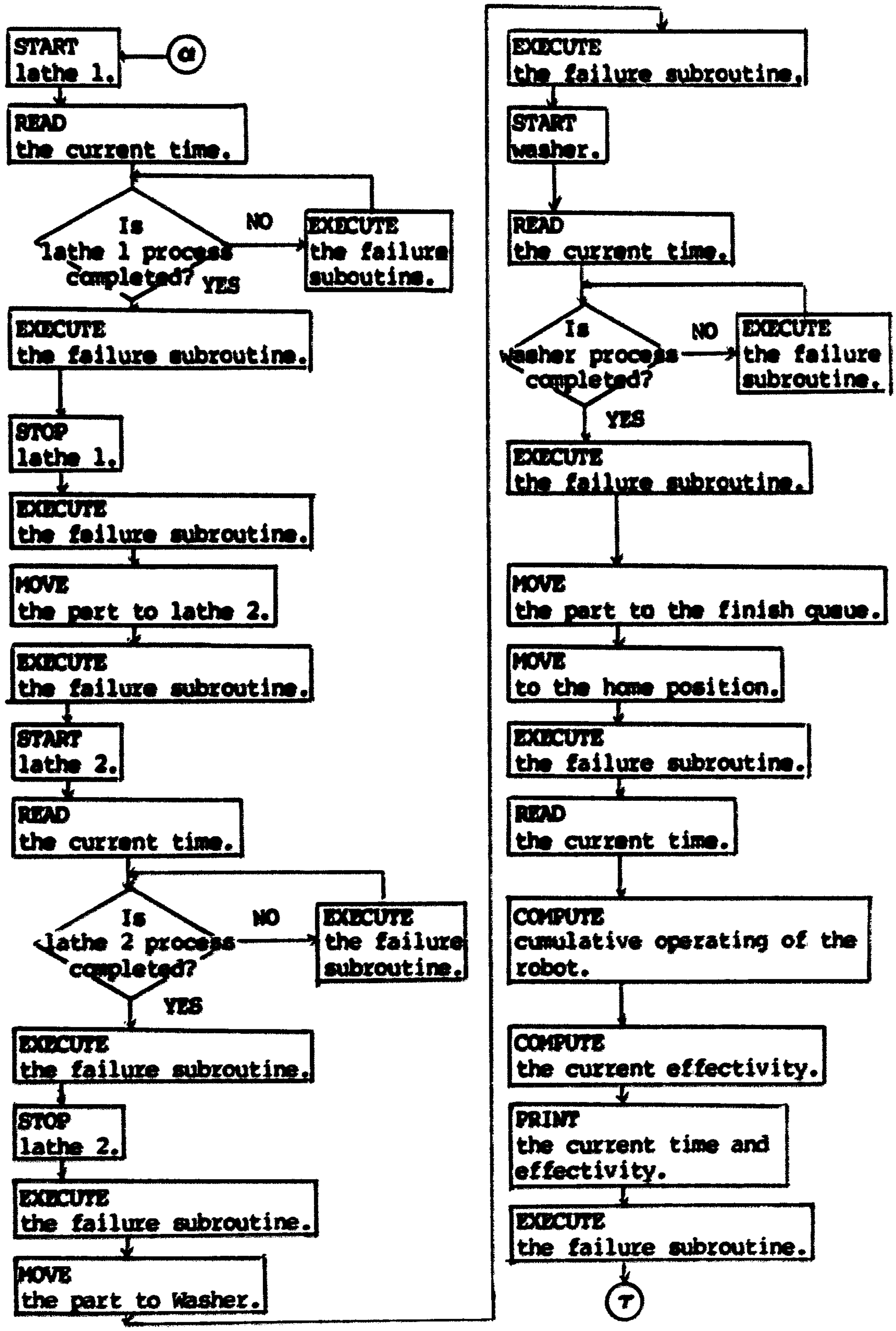



Figure 6-1a. (continued)

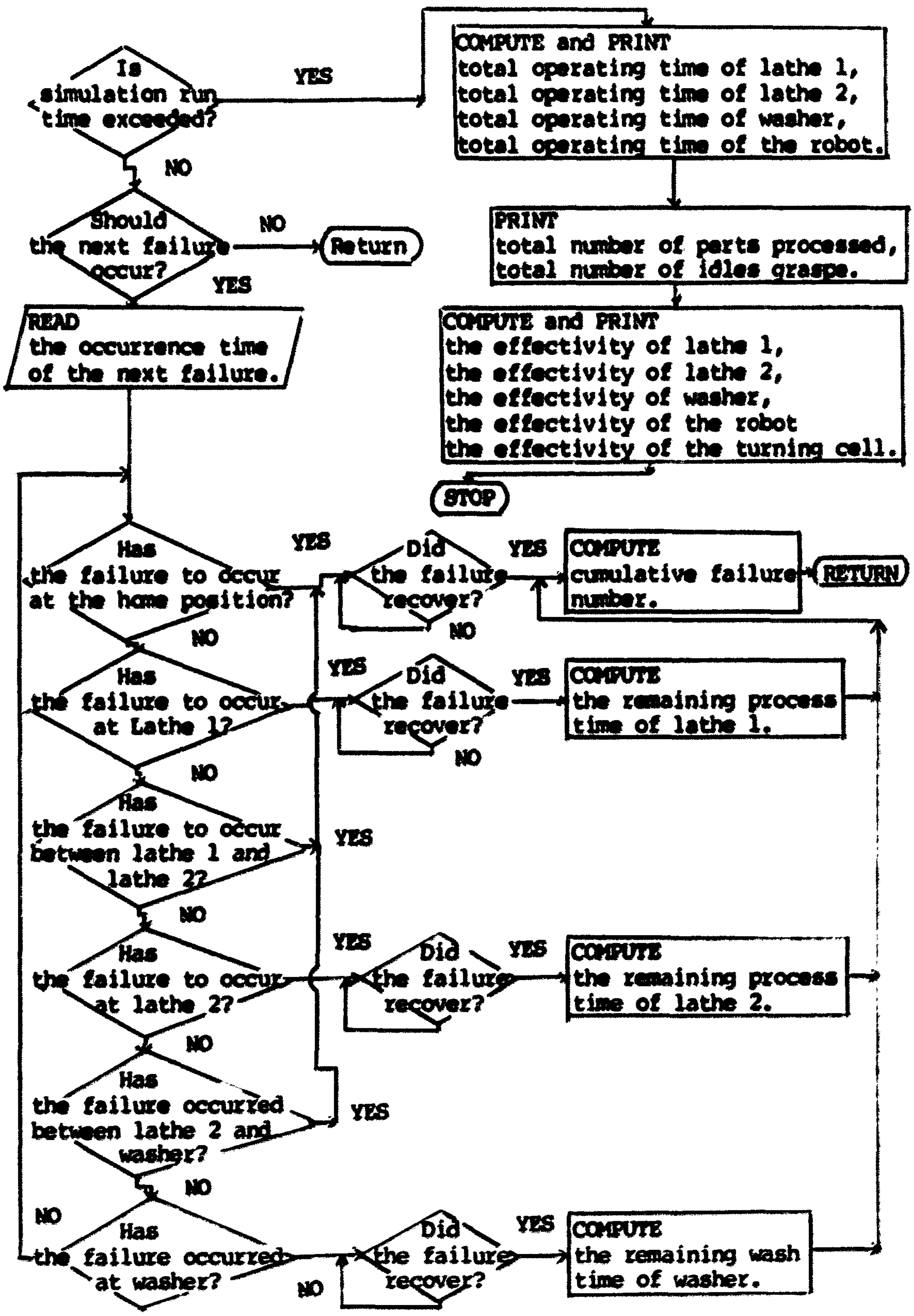



Figure 6-1b. Flow diagram of failure subroutine

Table 6-1. Variables used in robot control software

| Variable | Loop counter (% = integer) | Description |
|---|---|---|
| A1(I%) | I% = 1, 2, ---, 61 | The number of steps for base. |
| A2(I%) | I% = 1, 2, ---, 61 | The number of steps for shoulder. |
| A3(I%) | I% = 1, 2, ---, 61 | The number of steps for elbow. |
| A4(I%) | I% = 1, 2, ---, 61 | The number of steps for right wrist. |
| A5(I%) | I% = 1, 2, ---, 61 | The number of steps for left wrist. |
| A6(I%) | I% = 1, 2, ---, 61 | The number of steps for hand. |
| BD(I%) | I% = 1, 2, ---, 6 | Failure occurrence time (sec.) |
| DU(I%) | I% = 1, 2, ---, 6 | Failure time duration (sec.) |
| RC(I%) | I% = 1, 2, ---, 6 | Failure recovery time (sec.) |
| TM(I%) | I% = 0, 1, ---, 5 | Memory for the real time clock:<br>TM(0)= Month;<br>TM(1)= Day;<br>TM(2)= Year;<br>TM(3)= Hour;<br>TM(4)= Minute;<br>TM(5)= Second. |
| A | | The remaining cycle time of lathe 1 after its failure recovers. |
| B | | The remaining cycle time of lathe 2 after its failure recovers. |
| C | | The remaining cycle time of washer after its failure recovers. |
| D | | Part measurement in steps. |
| E1 | | Effectivity of lathe 1. |
| E2 | | Effectivity of lathe 2. |
| E3 | | Effectivity of washer. |
| E4 | | Effectivity of the robot. |
| EFF | | Effectivity of the turning cell. |
| G | | Part measurement in inches. |
| INDEX = 0 | | When no parts were available at the input queue. |
| = 1 | | When the robot had a part at the input queue. |

Table 6-1. (continued)

| Variable | | Description |
|---|---|---|
| II% | | An index to specify a position at which the robot failed. |
| | 1 <= II% <= 22 | The robot failed at the input queue. |
| | 23 <= II% <= 30 | The robot failed at lathe 1. |
| | 31 <= II% <= 42 | The robot failed between lathe 1 and lathe 2. |
| | 43 <= II% <= 50 | The robot failed at lathe 2. |
| | 51 <= II% <= 55 | The robot failed between lathe 2 and washer. |
| | II% >= 56 | The robot failed at washer. |
| J | | Cumulative number of parts processed by the turning cell. |
| K | | Total number of failures. |
| L1 | | Lathe 1 cycle time (sec.). |
| L2 | | Lathe 2 cycle time (sec.). |
| WT | | Washer cycle time (sec.). |
| M | | Cumulative idle grasps of the robot due to no presence of a part in the input queue. |
| N | | Counter for failures. |
| RR | | Cumulative robot operating time (sec.) |
| S | | Stepper motor speed. |
| S1 | | Cumulative processing time of lathe 1. |
| S2 | | Cumulative processing time of lathe 2. |
| S3 | | Cumulative processing time of washer. |
| SR | | Simulation run time of a decision rule set (sec.). |
| TE | | Current turning cell effectivity. |
| TX, W3, V6 | | Current simulation clock time (sec.). |
| WD | | Wait delay (sec.). |

Table 6-2. Robot control program structure[1]

| Line numbers | Description |
|---|---|
| 1 - 1280 | Main program. |
| 1 - 9 | program heading. |
| 10 - 180 | input data. |
| 185 - 200 | set the real time clock. |
| 240 - 280 | move to the home position. |
| 290 - 380 | check to see if the input queue has a part. |
| 390 - 415 | no part available at the input queue. |
| 420 - 550 | compute the turning cell effectivity. |
| 600 - 1280 | move a part to lathe 1, lathe 2 and washer in order to process. Return to the home position after a processed is put on the finish queue. |
| 10000 - 40110 | Subroutine for failures of the robot. |
| 10000 - 10050 | check to see if a failure occurred in the robot. |
| 20000 - 20110 | determine the current position at which the robot failed. |
| 30070 - 40110 | determine the recovery time of each failure. Also, determine the remaining process time of each lathe and washer after the failure recovers. |
| 41000 - 41010 | Subroutine for the robot's movement. |
| 45000 - 50200 | Subroutine for computing the turning cell statistics. |
| 45000 - 45010 | check to see if the simulation run time has been exceeded. |
| 50000 - 50210 | compute and print all statistics related to lathe 1, lathe 2, washer and the robot. |

1. See Appendix E.

intermediate points between each functional location to avoid collision with the model components.

At the beginning of each simulation, the robot moved from the

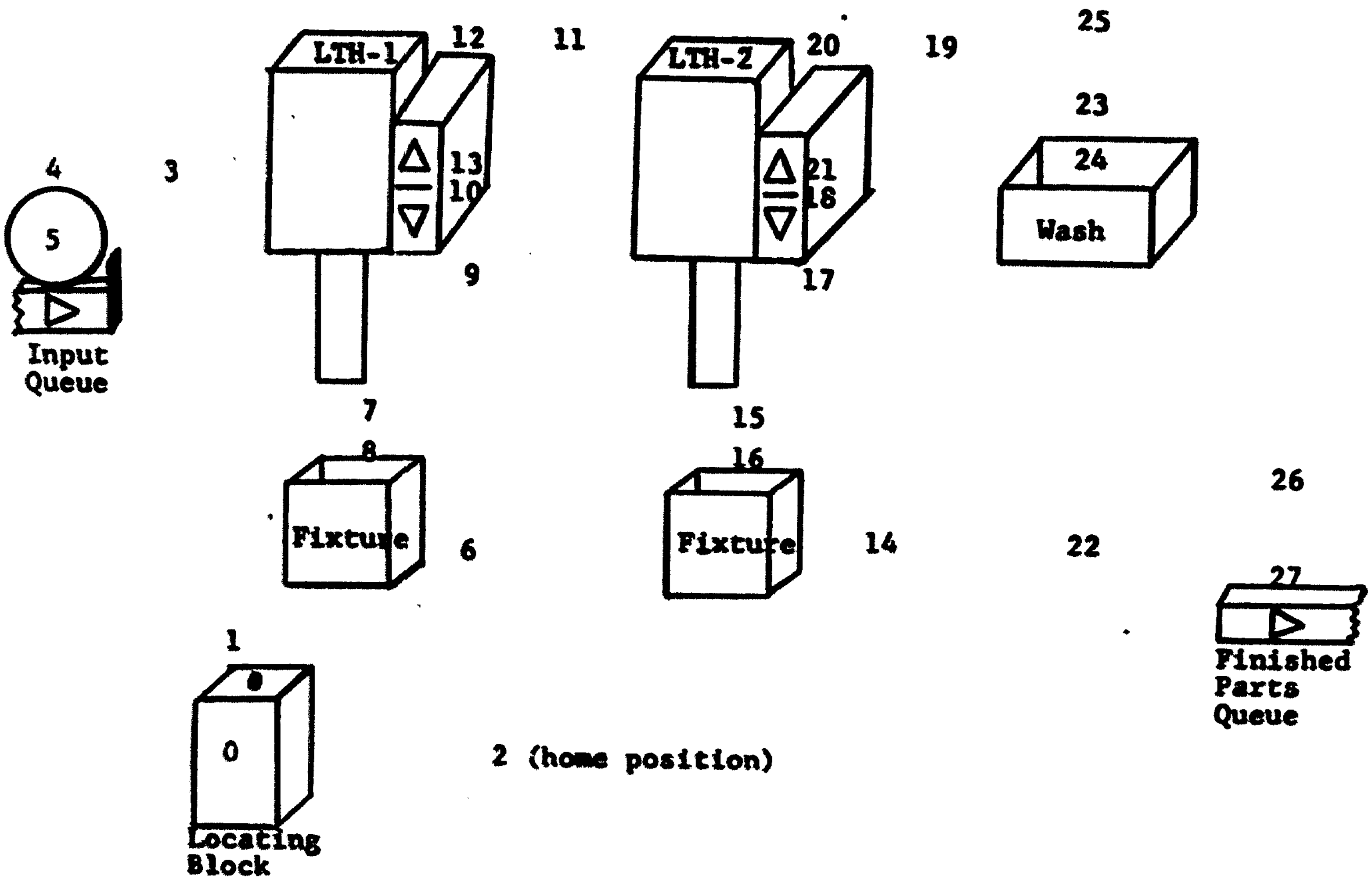



Figure 6-2. Overview of robot movement locations

locating block to location 1. After the real time clock was set and displayed on the TRS-80 screen, the robot then moved to location 2 which was the home position. After checking to see if the robot failed, a fixed wait delay was executed. As soon as the wait delay ended, the effectivity of the turning cell was computed, and the robot proceeded through locations 3, 4 and 5. The program then instructed the robot to close its hand and measure how far the hand closed. If a part was not present, the robot moved to the home position. The program updated the cumulative number of idle grasps and again executed the wait delay. The failure checking procedure was repeated at this point.

If a part was found at the input queue, the robot took the part and moved through Locations 4, 3, 2, 6, 7 and 8. This sequence of positions loaded the part on the Lathe 1 fixture. The robot was again checked to see if a failure was scheduled to occur. The robot then moved from location 8 to locations 7, 6, 9 and 10 to turn the lathe on. It then retraced its steps to location 6 where it waited until the machining cycle was completed. During the waiting time, the failure checking procedure was executed repeatedly.

The robot next moved to locations 11, 12 and 13 to turn the lathe off. By again retracing its steps, the robot was able to remove the part from the lathe 1 fixture and proceed to lathe 2. The failure checking procedure and the computation of statistics were repeated for lathe 2 and the washer until the part was finally placed on the finished parts queue. The robot then moved back to the home position before checking the input queue for another part.

Table 6-3 presents a complete list of the robot's stepper motor counts for the 27 locations. To move the robot from one location to another, the robot was instructed to move the difference between the step counts of the two locations. For example, to move from Location 4 to Location 5, the command issued would be '@STEP 50, 666, 558, -646, -347, 373, 0'. The robot motor speed, S, used for the simulations was 50 which is 185 steps per second.

## 5. Failures

The robot failed five times during the simulation. As described in Chapter 5, the mean time between failures (MTBF) was 78.6511 hours. Utilizing the MTBF, the random failure occurrence times were generated by a exponential random number generator. The repair time was fixed in each failure. Table 5-11 in Chapter 5 presents five failure occurrence times and recovery times.

## 6. Startup procedure

The first step in the operation of the robot control software was to load the ARMBASIC program into the TRS-80 memory. When the TRS-80 is initially turned on, the prompt "CASS" is displayed on the screen. In response, the user types "L" and presses the "ENTER" key. The next prompt is "MEMORY SIZE?" The user presses the "ENTER" key in response. The user next types "SYSTEM" and presses "ENTER". The screen then displays a "*?" prompt. In response, the user loads the ARMBASIC program into the TRS-80 cassette recorder, types "ARMBASIC," presses "ENTER," and presses the "PLAY" button on the recorder. The ARMBASIC program is then loaded into TRS-80 memory. After loading,

Table 6-3. Robot stepper motor counts

| Location # | Motor A | Motor B | Motor C | Motor D | Motor E |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 0 | -532 | 16 | 0 | 0 |
| 2 | 0 | -792 | -41 | 388 | -380 |
| 3 | 0 | -1736 | 870 | 388 | -380 |
| 4 | 11 | -1031 | 903 | 375 | -393 |
| 5 | 11 | -989 | 792 | 375 | -393 |
| 6 | 677 | -431 | 146 | 28 | -20 |
| 7 | 677 | -283 | 304 | 28 | -20 |
| 8 | 677 | -283 | 304 | 46 | -38 |
| 9 | 759 | -362 | 324 | 28 | -20 |
| 10 | 759 | -362 | 324 | -5 | 13 |
| 11 | 837 | -519 | 398 | 28 | -20 |
| 12 | 766 | -519 | 398 | 28 | -20 |
| 13 | 766 | -519 | 398 | 63 | -55 |
| 14 | 1150 | -419 | 135 | 31 | -23 |
| 15 | 1150 | -282 | 291 | 31 | -23 |
| 16 | 1150 | -282 | 291 | 42 | -34 |
| 17 | 1192 | -492 | 232 | 31 | -23 |
| 18 | 1192 | -492 | 232 | 0 | 8 |
| 19 | 1360 | -631 | 284 | 0 | 8 |
| 20 | 1184 | -631 | 284 | 0 | 8 |
| 21 | 1184 | -631 | 284 | 27 | -19 |
| 22 | 1563 | -419 | 135 | 31 | -23 |
| 23 | 1563 | -822 | 667 | 373 | -365 |
| 24 | 1563 | -284 | 509 | 373 | -365 |
| 25 | 1563 | -1000 | 844 | 373 | -365 |
| 26 | 2141 | -1000 | 844 | 373 | -365 |
| 27 | 2141 | -896 | 736 | 269 | -469 |

The hand motor (motor F) is omitted from this table. This is because the jaw open/close movement relates only to grasping or releasing a part and not to the location of the robot.

the following display appears on the screen:

ARMBASIC
VERSION 2.X
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The user must next rewind and remove the ARMBASIC cassette from the recorder. The robot control BASIC program is next placed in the recorder. The user types "CLOAD ROBOT CONTROL" presses "ENTER" the "PLAY" key on the recorder. When the program is loaded, "READY" will appear on the screen. The user types "RUN" when ready to execute the simulation. In response to the run command, the following prompt appears on the screen:

ENTER SIMULATION TIME IN MINUTES

In reponse, the user enters the desired simulation time and presses "ENTER." The user is then prompted to enter the desired stepper motor speed, cycle times for lathe 1, lathe 2, the washer and the wait delay. After the cycle times have been entered, the following prompt appears:

SET HOME POSITION AND THEN PRESS 0

The robot can then be manually positioned in reference to the locating block. For proper cycle operation, the hand must be in a horizontal position with the tip of the hand at the rear of the locating block. After the hand has been positioned at the correct reference point, the user initiates the program cycle by pressing the "0" key and then "ENTER." The robot then operates automatically until the user halts the operation by pressing the "BREAK" key.

## C. Model Control Software

### 1. Overview

In this research, the total number of model control software programs was twenty-eight. This is because twenty-eight different decision rule sets were evaluated. Each software program is described in detail in the following sections.

The model control software written in BASIC was executed on the CBM computer. It consisted of two types of logic. The first type involved commands used to send and receive signals to and from the model. These I/O commands were of the following format:

```
output - POKE 59471, X
input  - POKE 59471, X
         PEEK(59471)
```

where:
X = model location number of the I/O devices shown in Figure 3-2.

The second type of control logic concerned the operation of the model as an automated flexible manufacturing system. This logic included the following features:

- Part selection procedure;
- Machine center selection procedure;
- Fetching procedure;
- Routing procedure;
- Machining procedure;
- Retrieval procedure;
- Failure checking procedure;
- Computation of the system statistics.

### 2. Program structure

Each control program by which a decision rule set was simulated consisted of seven basic subroutines: the retrieval procedure subroutine, the part selection/machine center selection subroutine, the part routing subroutine, the machine process completion subroutine, the turning cell process completion subroutine, and the failure subroutine. Seven basic subroutines are shown in Table 6-4. Figure 6-3 illustrates a flow chart depicting the relationship between the main program and the subroutines. Each number represents the first line number of each subroutine. The center section of Figure 6-3 is the main program. The subroutines were continueously executed until a specified simulation run time was completed.

A general flow diagram of the model control software program is presented in Figure 6-4. One full program list requires ten pages. When the twenty-eight decision rule sets are listed, the total number of pages becomes 280. Selected program listings are presented in Appendix F. Appendix F contains the program listings for the following decision rule sets:

- RANDOM/RANDOM
- FSFS/FMFS
- SPT/WINQ
- DDATE/WINQ
- SLACK/WINQ
- S/PT/WINQ
- VALUE/FMFS

3. Startup procedure

Upon energizing the CBM, the following display appears on the screen.

* * * COMMODORE * * *

31743 BYTES FREE

READY

The user loads the control program into CBM memory by typing the

Table 6-4. Model control program structure

| Line numbers | Description |
|---|---|
| 5 - 780 | Main program. |
| 5 | open the CBM 4023 printer. |
| 10 - 50 | program heading. |
| 100 - 120 | set dimensions for system variables. |
| 130 - 160 | initialize the I/O function of the multiplexer. |
| 170 - 340 | initialize model control variables. |
| 350 - 440 | read part numbers allocated to seven storage areas. |
| 441 - 443 | read part family numbers. |
| 445 | initialize the process completion time of parts. |
| 450 - 499 | read input data. |
| 500 - 560 | adjust manually all necessary gates in the model. |
| 580 - 590 | enter the simulation run time of a decision rule set. |
| 620 - 630 | set the internal clock to zero. |
| 650 - 670 | read failure data for the model components. |
| 700 - 780 | model control main subroutines. |
| 10000 | Subsubroutine for the current clock. |
| 11000 - 11170 | Subroutine for part selection and machine center selection. |
| 12000 - 12220 | Subsubroutine for part fetching operation. |
| 13000 - 13550 | Subroutine for part routing operation. |
| 14000 - 14040 | Subsubroutine for machining operation. |
| 16000 - 16040 | Subsubroutine for updating the current system status. |
| 17000 - 17130 | Subsubroutine for part selection. |
| 17500 - 17620 | Subsubroutine for machine center selection. |
| 18000 - 18230 | Subsubroutine for computing system's intermediate statistics. |

Table 6-4. (continued)

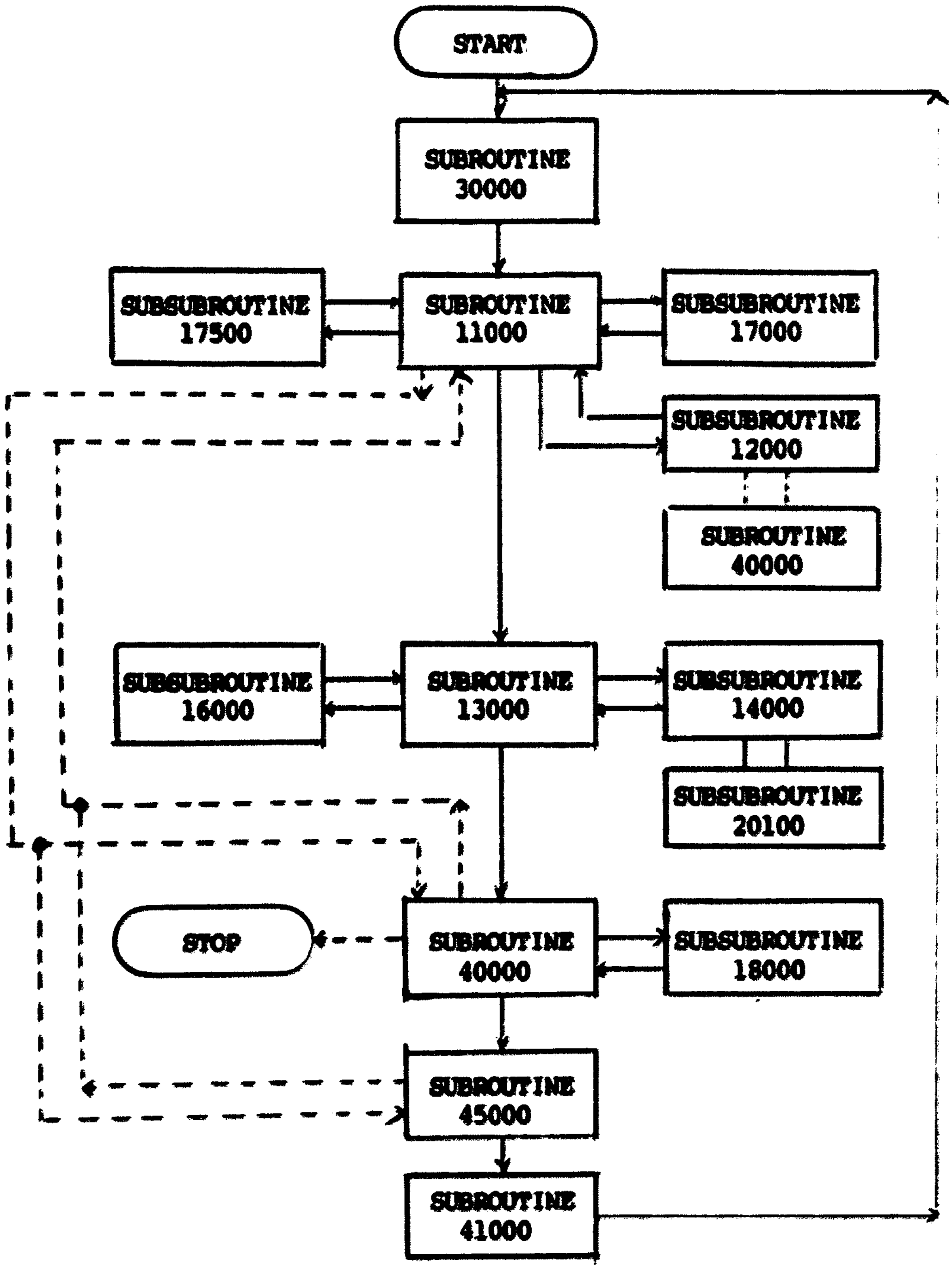
| Line number | Description |
|---|---|
| 20100 - 20220 | Subsubroutine for machining operation. |
| 30000 - 30330 | Subroutine for the retrieval process. |
| 35000 - 35010 | Subsubroutine for determining the original storage area of a returning part. |
| 40000 - 40580 | Subroutine for finishing the machine center process and the simulation run time. |
| 41000 - 41620 | Subroutine for failure checking procedure. |
| 45000 - 45220 | Subroutine for the turning cell finish queue. |
| 50900 - 50910 | Close the CBM 4023 printer. |

command "LOAD (a name of decision rule set)." Next, the user loads the program tape into the CBM cassette recorder. The "ENTER" key on the CBM keyboard and the "PLAY" key on the cassette recorder are then depressed. The following messages appear on the screen:

```
SEARCH FOR (a name of decision rule set)
FOUND (a name of decision rule set)
LOADING (a name of decision rule set)
```

When the CBM has completed reading the tape, a "READY" prompt appears on the screen.

All times were measured by the CBM internal clock. The minimum unit of the clock is a "JIFFY." One jiffy is equal to 1/60 of a second. Therefore, one minute of real time equals 3600 jiffies. The CBM clock is accessed by reading the value of the variable TI. After completion of any desired changes in the program, the user may exe-




. ————————> : Basic information flow line;
. - - - - - - -> : Optional information flow line.

Figure 6-3. Relationship between subroutines

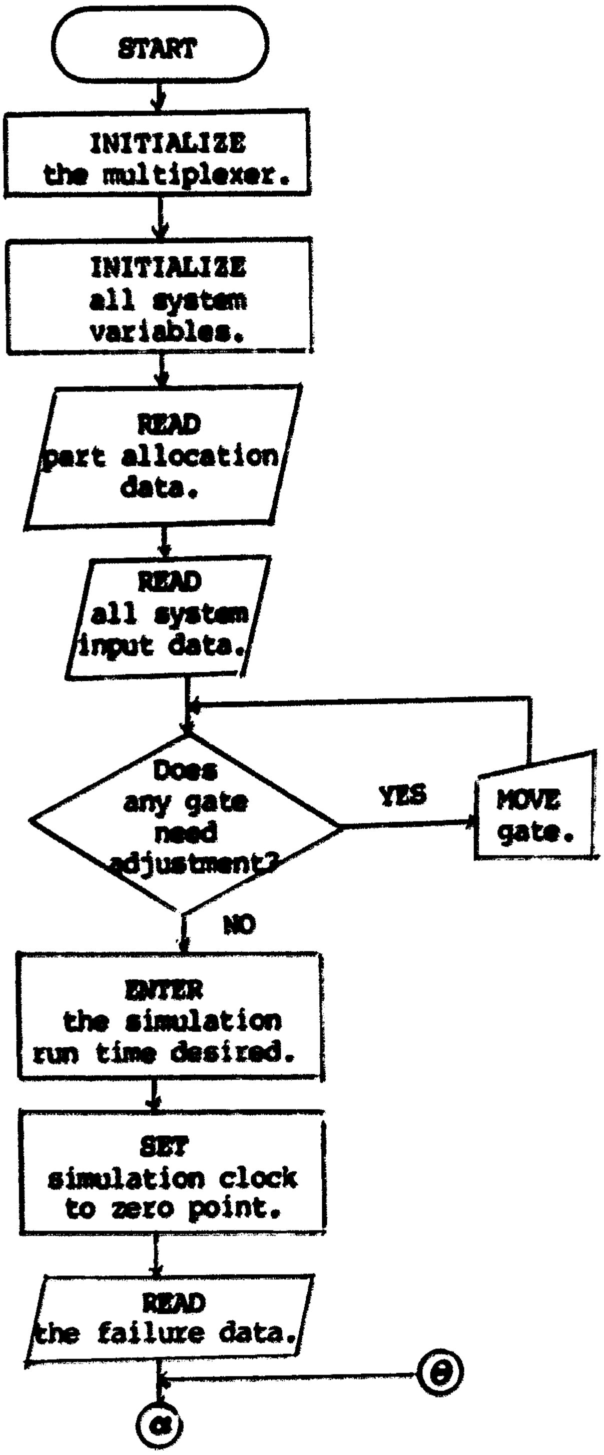



Figure 6-4. General flow chart of the model control

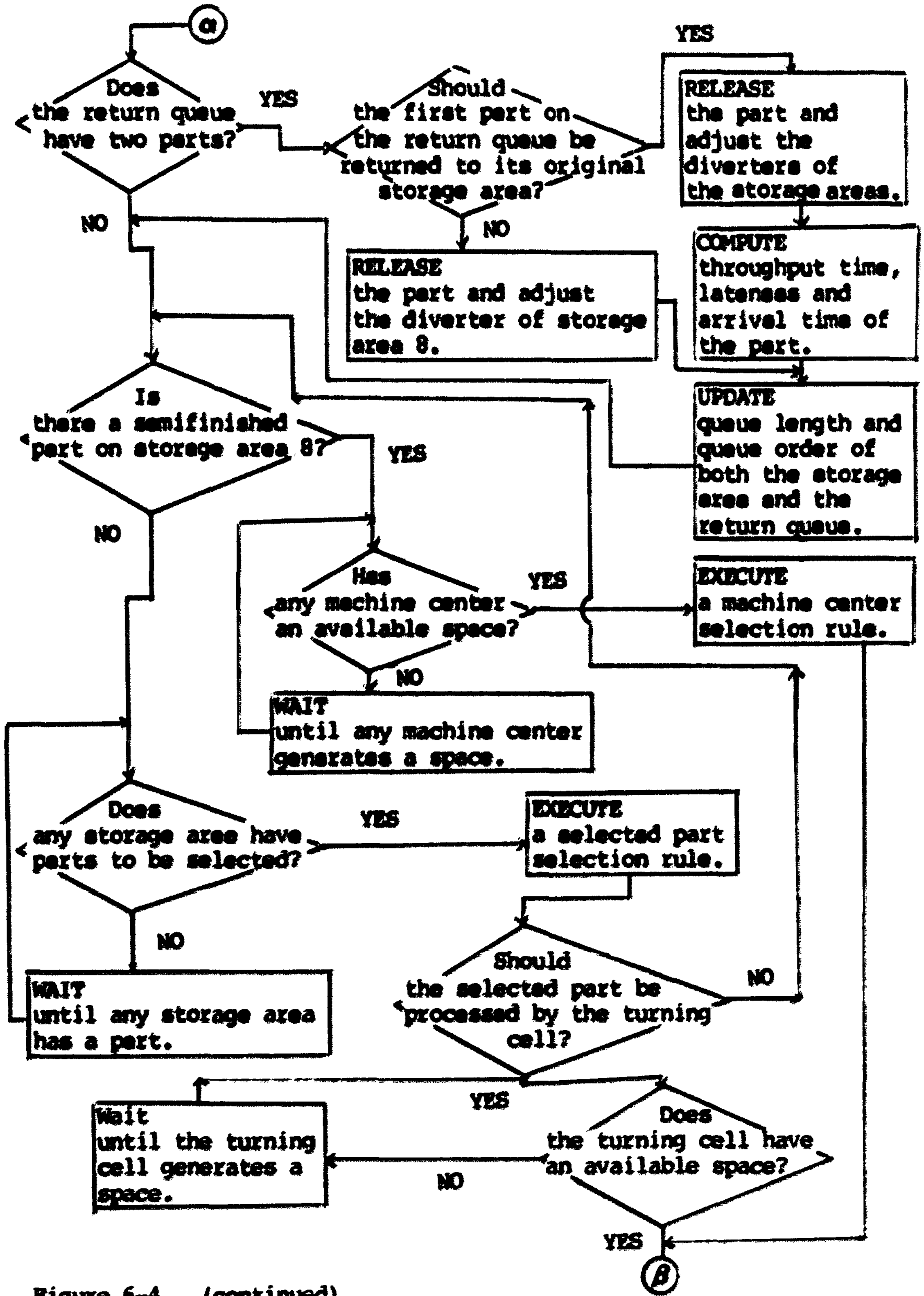



Figure 6-4. (continued)

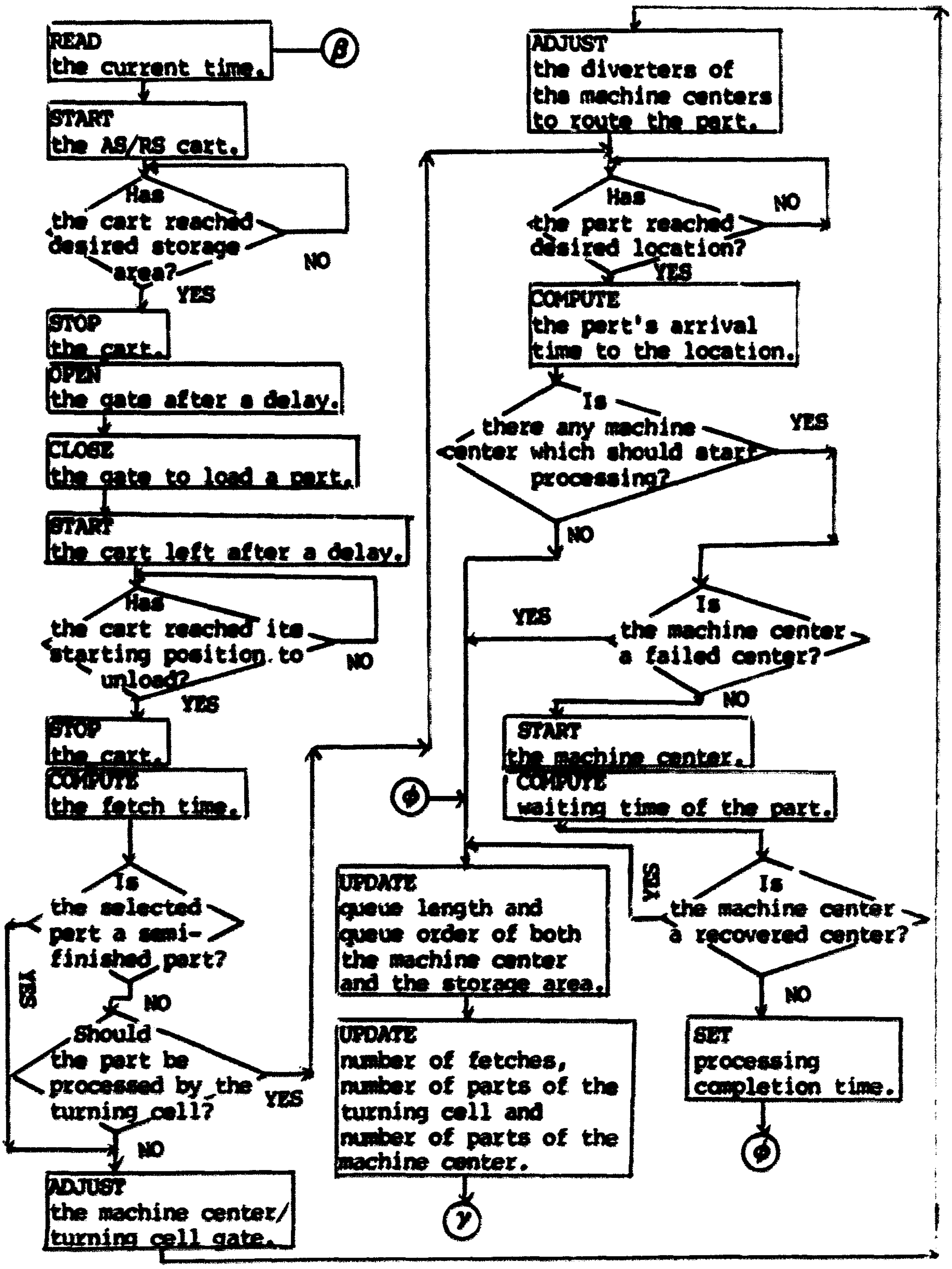



Figure 6-4. (continued)

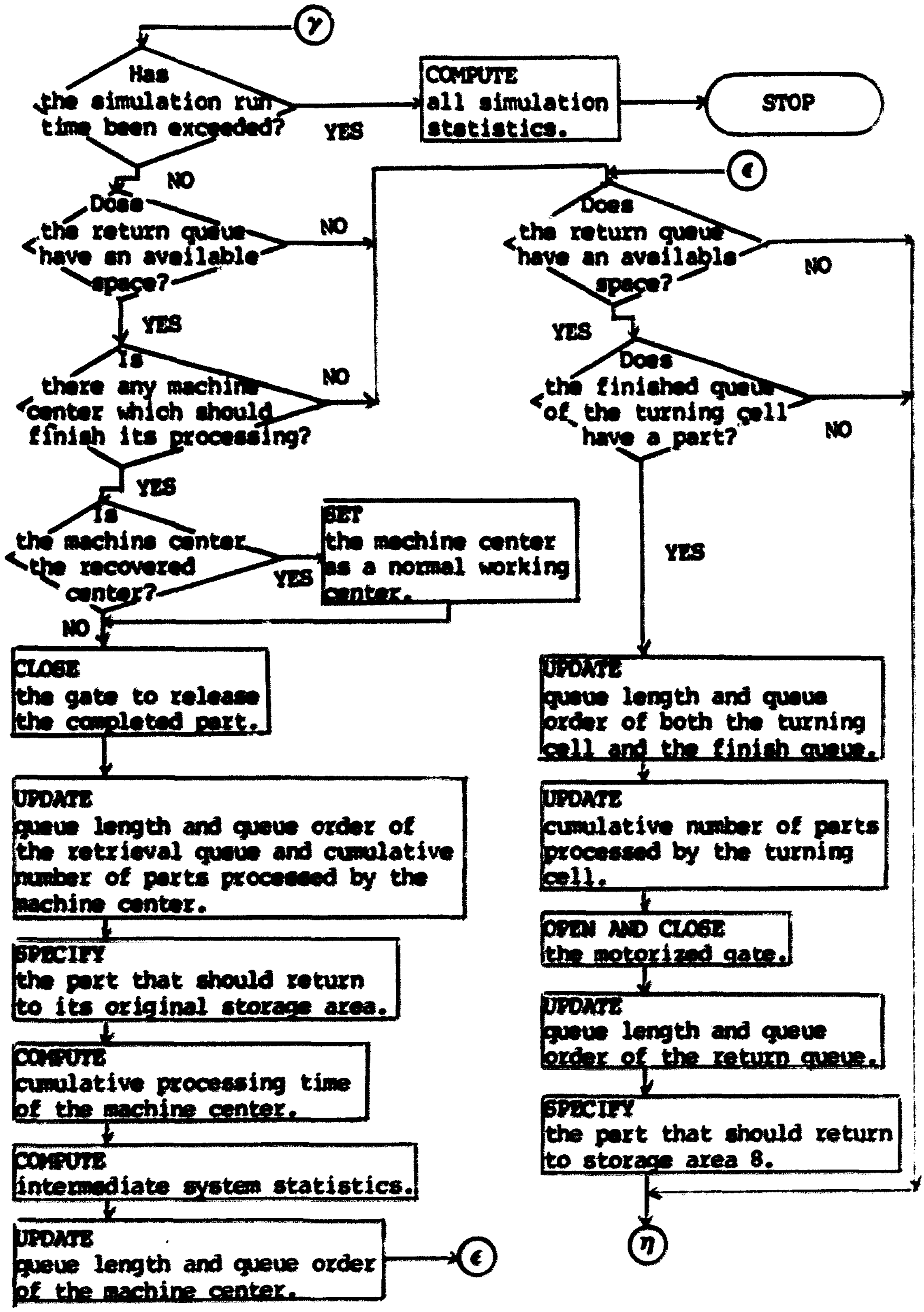



Figure 6-4. (continued)

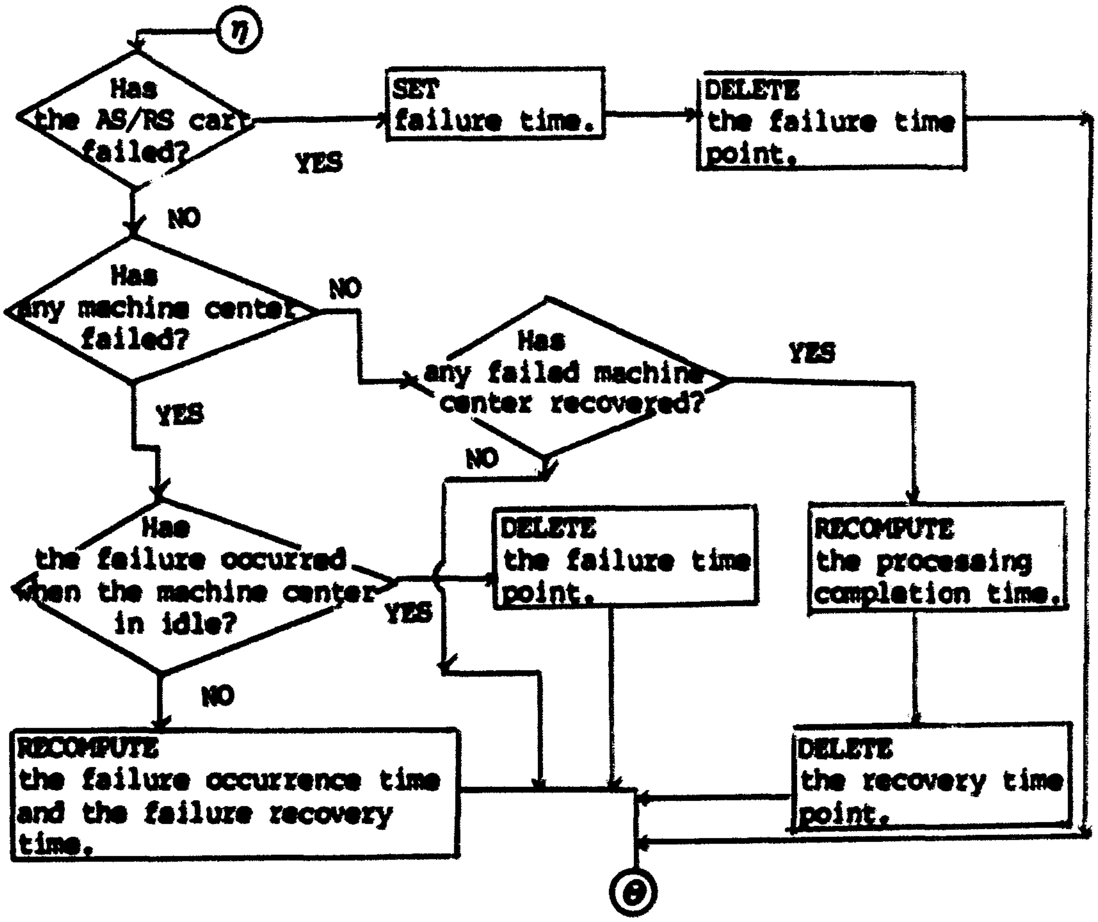



Figure 6-4. (continued)

cute the program by issuing the "RUN" command and pressing "ENTER."

As soon as the "RUN" command is executed, the CBM 4023 printer is ready to print all required statements and the simulation statistics of each decision rule set. This execution was completed by the following statements:

```
OPEN 1,4
CMD 1
```

where:

1 = a file number;
4 = a device number.

The printer was closed by the statements of PRINT#1 and CLOSE1 after the simulation was completed.

4. Intialization of variables

The program first intialized the variables used in the program. Table 6-5 shows a list of the variables used in each of twenty-eight model control software programs.

Three statements initialized the I/O function of the multiplexer (3). The statement "POKE 59459, 127" sets PA0 - PA6 (I/O lines) of the parallel user port of the CBM computer to output modes and sets PA7 to an input mode. The statement "POKE 59467, PEEK(59467) and 227" and "POKE 59468, PEEK(59468) and 31 or 224" enable the CB2 output of the parallel user port and holds it at high state. This allowed output information to pass through the multiplexer to the model.

5. Allocation of parts

As mentioned previously, the FMS mdel processed seven different part families which were allocated to seven different storage areas. Each family consisted of five identical parts. This allocation was shown in Figure 3-4 in Chapter 3.

For the model control software, each part had a specific two-digit number. The first digit represented a part family. The second digit represented a storage area. Figure 6-5 shows the allocation of parts with the assigned numbers.

When the user typed the "RUN" command and pressed "ENTER," the model control software read the two-digit part numbers as input data after the initialization of variables.

Table 6-5. Variables used in model control software

| Variable | Loop counter | Description |
|---|---|---|
| AL(I) | I = 1, 2, ---, 7 | Allowances to determine the due-dates of part family I. |
| AT(I) | I = 1, 2, ---, 77 | Arrival time of part I to its original storage area. |
| BF(I) | I = 1, 2, ---, 70 | I th failure recovery time. |
| BO(I) | I = 1, 2, ---, 70 | I th failure occurrence time. |
| CP(I,J) | I = 1, 2, ---, 6<br>J = 1, 2, ---, 6 | Cumulative time of I th machine center queue which had J parts. |
| D(I) | I = 1, 2, ---, 30 | Gate status (1: open, -1: close). |
| DF(I) | I = 1, 2, ---, 8 | Cumulative number of parts fetched from storage area I. |
| DT(I) | I = 1, 2, ---, 6 | Cumulative number of parts routed to machine center I. |
| DU(I) | I = 1, 2, ---, 70 | Failure time of I th failure. |
| DX(I) | I = 22, 23, ---, 27 | Failure status of machine center I: |
| | DX(I)= 1 | machine center I failed; |
| | DX(I)= 2 | failed machine center I recovered; |
| | DX(I)= 10 | normal machine center operation. |
| EM(I) | I = 1, 2, ---, 6 | Effectivity of machine center I. |
| ID(I) | I = 1, 2, ---, 77 | Waiting time of part I to be processed by a machine center. |
| IM(I) | I = 1, 2, ---, 6 | 1 - EM(I). |
| LA(I) | I = 1, 2, ---, 77 | Production lateness of part I. |
| LQ(I) | I = 1, 2, ---, 30 | Number of parts in Location I queue. |
| MN(I) | I = 1, 2, ---, 70 | Number of machine center for I th failure. |
| MO(I) | I = 1, 2, ---, 6 | Cumulative number of parts processed by machine center I. |

Table 6-5. (continued)

| Variable | Loop counter | Description |
|---|---|---|
| MP(I) | I = 1, 2, ---, 7 | Process time of part family I to be processed by the FMS model. |
| OQ(I,J) | I = 1, 2, ---, 30<br>J = 1, 2, ---, 5 | Part number of location I with J th order. |
| PN(I,J) | I = 1, 2, ---, 30<br>J = 1, 2, ---, 5 | Part family number of location I with J th order. |
| PP(I) | I = 1, 2, ---, 6 | Process time of machine center I. |
| PT(I) | I = 1, 2, ---, 7 | Process time of part family I. |
| RL(I) | I = 1, 2, ---, 77 | An index for specifying part I in the retrieval procedure: |
| | RL(I)= 1 | part I should return to its original storage area as a raw material; |
| | RL(I)= 2 | part I should return to storage area 8 as a semifinished part. |
| RO(I) | I = 1, 2, ---, 6 and 16 | Route time to machine center I or the turning cell input queue. |
| RR(I),<br>RT(I) | I = 1, 2, ---, 6 | Cumulative process time of machine center I for parts routed to the machine center. |
| T1(I) | I = 1, 2, ---, 77 | The current time at which the AS/RS cart started to fetch part I. |
| TF(I) | I = 1, 2, ---, 77 | Process completion time for part I. |
| TP(I) | I = 1, 2, ---, 77 | Throughput time of part I. |
| TR(I) | I = 1, 2, ---, 77 | Arrival time of part I to a machine center or the turning cell input queue. |
| T$(I) | I = 1, 2, ---, 70 | A failed component name for which the I th failure occurred. |
| W3(I,J) | I = 1, 2, ---, 8<br>J = 1, 2, --, 6 and 16 | The sum of DELAY-1 and normalization delay in fetching operation for a path from storage area I to machine center J. |

Table 6-5. (continued)

| Variable | Loop counter | Description |
|---|---|---|
| W6(I) | I = 1, 2, ---, 8 | Returning time to storage area I from the retrieval queue. |
| VL(I) | I = 1, 2, ---, 7 | Dollar value of part family I. |
| XX(I) | I = 22, 23, ---, 27 | Process completion time of the failed machine center. |
| E1 | | Average effectivity of the machine center cell. |
| EA | | Effectivity of the AS/RS cart. |
| F, FF | | A storage area number. |
| FT | | Fetching time of the AS/RS cart for every part. |
| IA | | 1 - EA. |
| IT | | 1 - E1. |
| M1 | | Total number of parts provided to the machine center cell. |
| M2 | | Total number of parts provided to the turning cell. |
| M3 | | Total number of outputs from the machine center cell. |
| M4 | | Total number of semifinished parts processed by the turning cell. |
| N | | Total number of parts fetched from the AS/RS cell. |
| SM | | Cumulative fetching time of the AS/RS cart to fetch parts. |
| SU | | Cumulative process time of the machine center cell. |
| T3, T5, T6, T7, T8, TM, XB | | Variables for reading the current clock. |

Table 6-5. (continued)

| Variable | Description |
|---|---|
| T, TJ, TH, TN, TT, KL, NC | Machine center number. |
| TD | Cumulative waiting time of parts processed by the machine center cell. |
| TI | Internal clock of the CBM computer. |
| TL | Cumulative production lateness of parts processed by the FMS model. |
| TU | Cumulative throughput time of parts processed by the FMS model. |
| W1 | Failure time of the AS/RS cart. |
| W4, W5 | Fixed delay times in every fetch. |

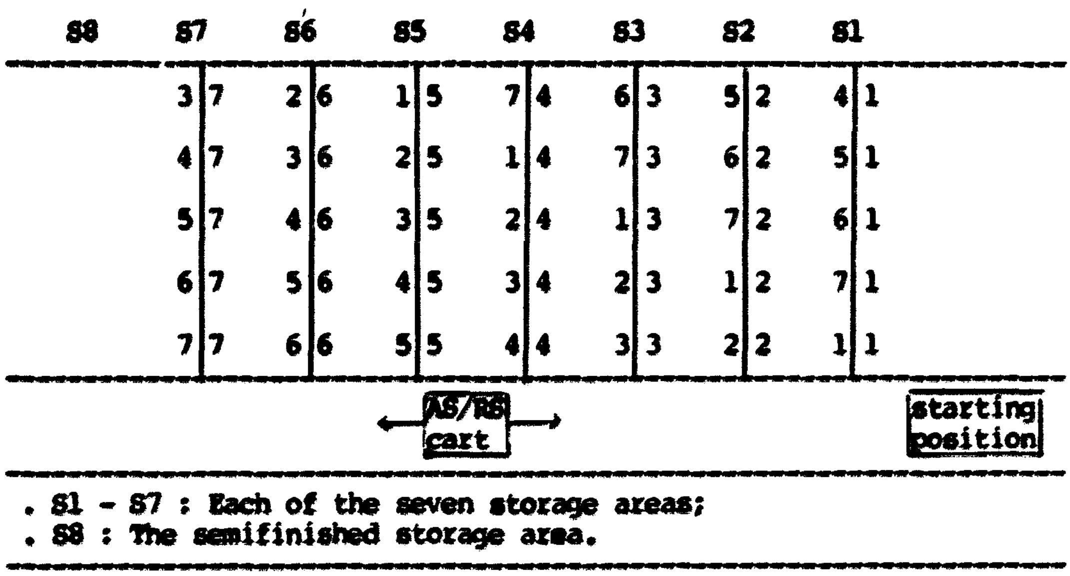



Figure 6-5. Allocation of parts

6. Read input data

Each decision rule set was simulated with the following input data:

- Seven sets of processing time data for seven part families;
- Seven dollar values for the seven part families;
- Seven allowance values to determine the due-dates of seven part families;
- Eight return time values to eight storage areas;
- Fifty-five values of the DELAY-1 plus the normalization delay under a decision rule set;
- Seven route time values for six machine centers and the turning cell;
- Simulation run time of a decision rule set;
- Seventy failure data points which included seventy failure occurrence times, failed components and failure durations of the AS/RS cart and the machine center cell. Recall that the failure data for the turning cell were stored on the TRS-80 computer.

All input data except the dollar value, return times and route times were adjusted by a time scaling factor in each decision rule set.

7. Gate adjustment

After reading the input data, the software was ready for the user to adjust the motorized gates in the model that required adjustment. Gates were adjusted by entering the appropriate number of the desired gate. All the gates in the model were closed in this manner to ensure their correct operation prior to a simulation run for each decision rule set.

8. Part selection and machine center selection (subroutine 11000)

Twenty-eight decision rule sets were simulated in this research. The major difference between sets was the part selection and machine center selection procedures used. This subroutine consisted of a part selection algorithm and machine center selection algorithm. The part selection rule was executed through subsubroutine 17000. The machine center selection rule was executed through subsubroutine 17500.

a. Part selection subsubroutine (subsubroutine 17000) This subsubroutine was executed with the following operating rules. The operating rules were used for continuing part selection until the simulation run time was completed.

- A semifinished part was fetched first whenever storage area 8 had a part;
- The first operation of parts 2, 4, 6 and 7 was processed by a machine center. The first operation of parts 1, 3 and 5 was processed by the turning cell. The second operation was processed by a machine center;
- If there was no part available in the storage area selected by a part selection rule, the next highest priority storage area was selected which had an available part;
- When no storage areas had available parts, part selection ceased until a machine center released its part to the retrieval queue and the processed part returned to its storage area. When this happened, normal part selection was not used. The part selection rule was converted to a first come-first serve (FCFS) rule until the storage areas were replenished.

There were seven different part selection subsubroutines which are described below.

- RANDOM - A new random number between 1 and 7 was assigned to a storage area in every fetch. The random number was equal to storage area number. The first part in the selected storage area was fetched.

- . FSFS - Storage area 1 had the highest priority, and storage area 7 had the lowest priority. As soon as the nearest storage area from the AS/RS cart station had a part, the storage area was assigned the highest priority.
- . SPT - A storage area was selected which had a part that had the shortest processing time.
- . DDATE - A storage area was selected which had a part that had the earliest due-date. The due-date was determined by the sum of the part's arrival time, processing time and its allowance. It was assumed that the first thirty-five parts arrived simultaneously at time 0 when the simulation started.
- . SLACK - A storage area was selected which had a part that had the least remaining slack time. The slack time of each part in every fetch was determined by (due-date - remaining processing time - current fetch time). It was assumed that the first thirty-five parts arrived simultaneously at time 0 when the simulation started.
- . S/PT - A storage area was selected which had a part that had the smallest ratio of slack time divided by the remaining processing time. The determination of the slack time and the part's arrival time was the same as the SLACK rule.
- . VALUE - A storage area was selected which had a part that had the highest dollar value.

All part selection rules except Rules RANDOM and FSFS were programmed in subsubroutine 17000 for each decision rule set. Rules RANDOM and FSFS selected an appropriate part using subroutine 11000 without subsubroutine 17000. Whenever a part selection rule was executed, the CBM specified the workcenter to which the selected part was routed. If a machine center had to process the selected part, a machine center selection algorithm was executed through subsubroutine 17500. Parts initially routed to the turning cell input queue did not require execution of subsubroutine 17500. In this case, however, there were two additional operating rules that applied:

- If the turning cell input queue was full with five parts, the CBM computer checked to see if the finish queue of the turning cell had a semifinished part. If there was a semifinished part, the part was released to the retrieval queue. A new space then was generated in the turning cell input queue. Then, the part selection was re-executed to select a part. If no semifinished parts were detected in the finish queue, the part selection was temporarily stopped until a space was generated;

- If the first part in every storage area was to be processed by the turning cell, the fetching operation paused until the turning cell released a semifinished part to the retrieval queue from the turning cell input queue.

b. Machine center selection subsubroutine (subsubroutine 17500)

This subsubroutine was executed using the following operating rules. The operating rules were used for continuing the machine center selection process until the simulation run time was completed.

- If a selected machine center was full with five parts, the next highest priority machine center which had an available space was selected;

- If all six machine centers were full with thirty parts, each machine center was checked to see if there was a completed part. If there was the completed part, the part was released to the return queue, and the machine center selection was re-executed.

Four different machine center selection rules were used:

- RANDOM - A new random number between 22 and 27 was assigned to a machine center in every fetch. The random number was equal to machine center number.

- FMFS - Machine center 1 had the highest priority, and machine center 6 had the lowest priority. As soon as the machine center nearest to the AS/RS cell generated a space for a part, the machine center was assigned the highest priority.

. NINQ - A machine center was selected which had the smallest number of parts including the currently processed part in its waiting line.

. WINQ - A machine center was selected which had the least amount of processing times including the currently processing part in its waiting line. For this rule, subroutine 18500 was called to compute total processing time of the machine center queue at every selection time.

Rules RANDOM and FMFS selected an appropriate machine center without subsubroutine 17500. As soon as both a part and a machine center were determined, the program proceeded to subsubroutine 12000 for the fetching the part.

9. Fetch subsubroutine (subsubroutine 12000)

This subsubroutine was called to send a signal to the AS/RS cart to proceed into the AS/RS cell. Before sending the signal, the program checked to see if the AS/RS cart failed during the fetch. The cart always failed and recovered at its starting position in every failure. The failure time of each failure was constant and is denoted by W1. When the cart recovered at its starting position, the program checked to see if there were completed parts in the machine center cell. The processed parts released to the return queue.

An electric signal was sent to the cart, then the cart moved to the specified storage area that had a viable part. The program then monitored the electric eye at the storage area. When the cart reached the proper area, the program sent a signal to the cart to stop. After a delay of W3, a signal was issued to the motorized gate of the storage area to open. The W3 included the normalization delay (mentioned in Chapter 4) which applied an uniform time scaling factor under each decision rule set. The following message was then displayed on the screen:

LOADING PART OQ(F,1) FROM STORAGE F

where F was a storage area.

A three second delay (W4) was executed to close the gate. Another 4.2 second delay (W5) was executed before a signal was sent to the cart to move out of the AS/RS cell. After the cart started to move, the following message was displayed:

RETURNING WITH OQ(F,1) FROM STORAGE F

where F was a storage area.

When the cart reached the starting position to unload the part, a fourth signal was issued to stop the cart. The part then rolled off the cart to the lifting ramp. While the part was moving up the lifting ramp, the computer determined the actual traveling time excluding any delay time. The following message was displayed:

FETCH TIME IS TA

where TA was a fetch time value in minute.

The computer updated the cumulative traveling time (SM) of the cart.

10. Part routing subroutine (subroutine 13000)

While the selected part was moving up the lifting ramp, the part routing subroutine was called to determine where the part should go. The desired routing location of parts 1, 3 and 5 was the turning cell input queue. For these parts, the machine center/turning cell gate was opened to route the part to the turning cell input queue. The following message was then displayed:

PART OQ(F,1) SHOULD GO TO TURNING CELL

where OQ(F,1) was a part number and F was a storage area.

The part next rolled over the input switch of the turning cell input queue. The program then computed arrival time (TR(OQ(F,1))) of the part to the turning cell.

If the selected part was one of parts 2, 4, 6 and 7, the part was routed to the machine center. The following message was then displayed:

PART OQ(F,1) SHOULD BE ROUTED TO MACHINE CENTER T

where OQ(F,1) was a part number and F was a storage area.

The machine center/turning cell gate was closed, and any motorized diverter which was not in the correct position to route the part to the proper machine center was adjusted.

The program then checked to see if the part reached the desired machine center. The arrival time of the part to the proper machine center was then computed. As soon as the part arrived at the turning cell or the machine center, the following subsubroutines were called:

a. Machining subsubroutine (subsubroutine 14000) In this subsubroutine, each machine center was checked to see if any part was waiting in a machine center queue to be processed. If a part was waiting and the machine center was idle, the part in the queue was processed on a FCFS (first come-first serve) basis. Subsubroutine 20100 was called to start processing. The machine center started processing by opening its motorized gate. A "failed" condition in any machine center is preventing the start of processing. The computer computed the waiting time for which the part had waited in the queue upon its arrival. Also, the cumulative waiting time of parts on the machin center was updated. The follow- ing message was next displayed:

> WAITING TIME OF OQ(TT,1) ON M/C TT IS ID(OQ(TT,1))
>
> where OQ(TT,1) was a part number, TT was a machine center and ID(OQ(TT,1)) was the waiting time.

The process completion time of the part was then determined. If the machine center was just recovering from its failure, the process completion time was determined in the failure subroutine described later.

<u>b. Updating subsubroutine (subsubroutine 16000)</u> After subsubroutine 14000 was executed, the program proceeded to subsubroutine 16000 to update both the queue length and the queue order of the storage area. The storage area provided a part to either a machine center or the turning cell. The location which received the selected part was also updated.

Both the queue length and the queue order of the location were updated.

After the above subsubroutines were executed, the current subroutine (subroutine 13000) continued updating the cumulative number of parts fetched for the turning cell operations or the machine center operations. The cumulative number of parts fetched from the storage area and the cumulative number of parts routed to the machine center cell were also updated. Every busy machine center was checked by subroutine 40000 to see if its processing should terminate.

11. Machine process completion subroutine (subroutine 40000)

This subroutine checked to see if the simulation run time was exceeded and if there were processed parts which should be released from the machine center cell. When the simulation was completed for a decision rule set, the program proceeded to compute all simulation statistics related to the performance criteria. The following statistics were generated by this subroutine:

. The AS/RS cart's effectivity and its idle rate;
. Each machine center's effectivity and its idle rate;
. Average effectvity of the machine center cell;
. Fetch rate of each storage area;
. Route rate to each machine center;
. Fetch rate for the machine center cell;
. Fetch rate for the turning cell;
. Total number of outputs from each machine center;
. Total number of outputs from the machine center cell;
. Total number of outputs from the turning cell;
. Total number of dispatches from the AS/RS cell;
. Current queue length of each storage area;
. Current queue length of the return queue;
. Current queue length of the turning cell;
. Current queue length of each machine center;
. Current queue order of each storage area;
. Current queue order of each machine center;
. Current queue order of the turning cell;
. Total fetch time of the AS/RS cart;
. Total processing time of the machine center cell;
. Total throughput time;
. Total production lateness;
. Total waiting time on the machine center cell.

After checking the simulation run time, each machine center which was busy processing a part was checked to see if the process should be completed. If a part was done and the retrieval queue had an available space, the following message was displayed:

PART OQ(TN,1) IS DONE AT LOCATION TN

where OQ(TN,1) was a part number and TN was a machine center.

The computer then sent a signal to the specified machine center to close its gate. After cumulative number of outputs from the machine center was increased by one, the processed part was released from the machine center and joined the return queue. The queue length of the return queue was increased by one and the queue order was updated. The program gave then the part an index of 1. This means that the part should return to its original storage area as a raw material. This subroutine then called a subsubroutine to compute the intermediate simulation statistics.

a. Intermediate statistics subsubroutine (subsubroutine 18000)

In this subsubroutine, the cumulative processing time of the machine center which released the processed part was computed. The following message was displayed:

TOTAL PROCESSING TIME OF M/C TN IS RT(NC)

where RT(NC) was the total processing time in minute, and both NC and TN were a machine center.

The intermediate average effectivity for both AS/RS cart and the machine center cell were computed next. The following message was displayed:

CURRENT TIME SYSTEM EFFECTIVITY

Recall that the turning cell effectivity at that time could not be added to compute the system effectivity because there was no communication link between the TRS-80 computer and the CBM computer. The turning cell effectivity was therefore computed by the TRS-80 computer. After the remaining parts' processing time of the machine center was computed, the following message was displayed:

REMAINING TIME OF M/C QUEUE TN IS CP(NC,LQ(TN)+1)

where CP(NC,LQ(TN)+1) was the remaining time, both TN and NC were a machine center, and LQ(TN) was the queue length of machine center TN.

Both the queue length and the queue order of the machine center were then updated.

12. Turning cell process completion subroutine (subroutine 45000)

When the CBM computer detected a semifinished part on the finish queue of the turning cell, the semifinished part was released when the return queue had an available space for the semifinished part. The cumulative number of semifinished parts was then increased by one. The following message was displayed:

PART OQ(TN,1) IS DONE AT LOCATION TN

where OQ(TN,1) was a part number and TN was a machine center.

The motorized gate of the finish queue was opened by a signal from the computer. After 2.4 second delay, the semifinished part was released to the return queue by closing the gate. The total number of parts on the turning cell was then decreased by one, and the queue order was updated. The queue length of the finish queue was also decreased by one, and the queue order was updated. After the total number of parts of the return queue was increased by one, an index was assigned to the semifinished part. This index was 2, and meant that the part should return to storage area 8.

13. Retrieval procedure subroutine (subroutine 30000)

To prevent mechanical malfunction of the return gate, the return queue had to always possess at least one part. If there was no part in the return queue, the next part released by a machine center or the turning cell was usually dropped outside the model as soon as the part hit the return gate. This malfunction occurred due to the part's accerated rolling spead.

Every part on the return queue was assigned a specific index. If the index was 1, the part was returned to its original storage area. Otherwise, the part was returned to storage area 8. When the index was 1, subsubroutine 35000 was called to determine a storage area to which the part should be returned.

a. Storage area determination subsubroutine (subsubroutine 35000) Recall that each part was represented by a two-digit number. The first digit represented its family, and the second digit represented its storage area. Whenever the family number was required by the program, the two-digit number was converted to a one digit number which represented the family number. Also, the two-digit number was converted to a one digit number which represented the storage area when the storage area number was required by the program.

After subroutine 35000 was executed, the following message was displayed:

PART OQ(30,1) SHOULD RETURN TO STORAGE FF

where OQ(30,1) was a part number and FF was a storage area.

The program then checked to see if the return lifting ramp was in the "down" position. If the ramp was down, the returning part rolled to the lifting ramp by opening/closing the motorized gate of the return queue. As soon as the lifting ramp started upward, the computer computed the throughput time (TP) of the part. The motorized diverters of the storage areas were then adjusted to the proper positions. This permitted the part to return to its raw material origin. The following intermediate statistics associated with the returning part were then computed:

- The throughput time;
- The production lateness;
- Cumulative throughput time of the processed parts;
- Cumulative production lateness of the processed parts;
- Arrival time of the part to its storage area as a raw material.

The queue length of the storage area was next increased by one, and the queue order was updated. The queue length of the return queue was also decreased by one, and the queue order was updated.

When the part's index was 2, the part was a semifinished part. The semifinished part was returned to storage area 8. No computations for intermediate statistics were made for parts returning to storage area 8.

14. Failure subroutine (subroutine 41000)

The total number of failures which occurred in the AS/RS cart and the machine center cell was 70. The failures of the turning cell were controlled by the TRS-80 computer. When the cart failed, the following message was displayed:

AS/RS CART FAILS. FAILURE NUMBER IS IC

where IC was the current failure number.

Failure time (W1) was determined and the failure point was deleted from the data. The value of W1 was considered as a delay in the fetch subroutine (subroutine 12000).

When one of the machine centers failed, two situations existed in executing the failure. One was for a busy condition, and the other was for an idle condition. When a machine center failed in an idle condition, the failure started immediately. The failure point was then deleted from the data. The following message was displayed:

MACHINE CENTER TJ FAILS AT BO(IC)/3600

where BO(IC) was the failure occurrence time, TJ was the failed machine center and IC was the current failure number.

When a machine center failed in a busy condition, the failure was executed immediately after the machine center finished its processing. In this situation, both the failure occurrence time and the recovery time had to be modified. This meant that the computer rechecked the machine center and implemented the failure with modified time values.

When failed machine center recovered, the following message was displayed:

FAILED MACHINE CENTER TJ IS RECOVERED AT BF(IC)/3600

where BF(IC) was the failure recovery time, TJ was the recovered machine center.

The process completion time of a part which had waited until the failed machine center recovered was then recomputed. The recovery point was then deleted from the failure data.

15. Summary

As shown in Figure 6-3, each program by which a decision rule set was simulated consisted of seven basic subroutines: the retrieval procedure subroutine, the part selection/machine center selection subroutine, the part routing subroutine, the machine process completion subroutine, the turning cell process completion subroutine and the failure subroutine. These subroutines were continuously executed until a specified simulation run time was completed.

From the machine process completion subroutine (subroutine 40000), all simulation statistics under a decision rule set were generated at the end of the simulation. All simulation statistics had to be converted to time values for the real system. There were twenty-eight different time scaling factors presented in Chapter 4. With the time scaling factors for twenty-eight decision rule sets, the simulation data were regenerated from the data of the model. Each decision rule set was then consistently compared with other decision rule sets.

Chapter 7 presents collected data which were hourly data regenerated from the scaled model data. Each decision rule set had a relative rank in each performance criteria from which the best decision rule sets were selected. An analysis procedure is also presented in Chapter 7 by which the performance of each decision rule set is evaluated.

# VII. DATA COLLECTION AND ANALYSIS PROCEDURE

## A. Introduction

Each of twenty-eight decision rule sets was simulated over 11 hours of model time. As described in Chapter 6, the simulation master clocks in both the CBM computer and the TRS-80 computer were set to zero when the simulation started. This means that the performance of a decision rule set was observed from the begining of the simulation. The master clock was incremented by a variable amount rather than by a fixed amount of time. The clock kept the simulated system running without interruption until an event occurred. At this point, the computer paused momentarily to record the change in the system. The computer kept track of when future simulated events were scheduled to occur. It jumped in simulated time to the next of these events, and updated the system. This cycle was repeated as many times as required during each of the simulations.

All simulations for the twenty-eight decision rule sets were experiments without repetitions. The long simulation run time (over 11 hours on the master clock) was the impetus for not repeating each of the simulation runs.

Whenever a simulation was completed for a decision rule set, the following statistics were tallied by the CBM computer:

- Fetch rate for each of the eight storage areas;
- Route rate for each of the six machine centers;
- Route rate for the turning cell;
- Total output from each of the six machine centers;
- Total output from the turning cell;

- Total model fetch time of the AS/RS cart;
- Total processing time in the machine center cell;
- Total waiting time in the machine center cell;
- Current queue length and its order for each of the eight storage areas, each of the six machine centers, the turning cell, and the return queue at the end of each simulation.

In addition, the CBM computer tallied the following intermediate simulation records for each decision rule set:

- Current reading of the simulation master clock;
- Part number loaded from a storage area at time t;
- Observed fetch time for a fetch;
- Part number routed to a machine center;
- Part number routed to the turning cell;
- Part number completed by a machine center;
- Part number returned from the return queue at time t;
- Throughput time, production lateness and arrival time of each return part at time t;
- Waiting time of a part on each machine center queue;
- Total processing time in each machine center;
- Average effectivity of the AS/RS cart and the machine center cell;
- Failed component, failure occurrence time, failure recovery time, and failure number.

The turning cell statistics were generated by the TRS-80 computer. The following statistics were obtained for the turning cell:

- Total processing times of lathe 1, lathe 2, the washing station and the robot (Mini-Mover-5);
- Total number of parts processed by the turning cell;
- Total number of idle grasps of the robot due to no presence of parts in the turning cell input queue;
- Effectivity of lathe 1, lathe 2, the washing station and the robot;
- Total effectivity of the turning cell.

The TRS-80 also determined the intermediate turning cell effectivity whenever the robot finished its cycle and failed at time t.

All simulation statistics were measured in model time. The model time was an adjusted time with a time scaling factor for a decision rule set. Each decision rule set had a specific time scaling factor described in Chapter 4. There were twenty-eight different time scaling factors. This means that all simulation statistics must be converted to real time values for consistent comparison of twenty-eight decision rule sets. That is, the model time was multiplied by a time scaling factor for each decision rule set. All performance criteria values except the actual production output presented in this chapter are the real time values regenerated from the model time under every decision rule set.

Specific data collected for each decision rule set are separately presented in this chapter. The analysis procedures for the obtained performance criteria values are presented as well.

## B. Data Collection

### 1. Overview

The detailed descriptions of six performance criteria were presented in Chapter 5. The six performance criteria are:

- Actual system effectivity;
- Traveling times for parts;
- Actual production output;
- Manufacturing throughput time;
- Work-in-process inventory;
- Production lateness.

Specific performance criteria values under every decision rule set were obtained after simulation times of approximately 11 hours.

### 2. Actual system effectivity

The actual system effectivity was defined as the ratio of the actual operation time required to produce parts divided by the available manufacturing time (simulation time). The effectivity was determined by effectivities of the AS/RS cart, the machine center cell and the turning cell. The determination of each of these factors was presented in Chapter 5. As another basic component, the automatic guided vehicle system (AGVS) of the actual FMS might have been merged to compute the actual system effectivity. However, no failures were assumed in the AGVS because the actual failure data were not available for this research. Therefore, the effectivity for the AGVS was omitted in computing the actual system effectivity.

The following values were required to determine the actual system effectivity for each of twenty-eight decision rule sets:

- . Total model fetch time of the AS/RS cart
- . Total processing time of the machine center cell;
- . Total processing time of the turning cell;
- . Simulation time for a decision rule set.

The total model fetch times were determined from both the observed model fetch time and the number of fetches from a storage area. The model fetch time presented in Chapter 4 was the average value of all observations from a storage area.

The total model fetch times were dependent upon which storage area was selected frequently under a decision rule set. Storage area 8 was the most distant storage area. Storage area 1 was the nearest area to the AS/RS cart's starting position. However, storage area 8 was independent of a part selection rule because semifinished parts stored on the storage area were always selected first. Therefore, storage area 7 was the most distant storage area which could be selected by a part selection rule.

The model fetch time did not include any failure times, idle times, and delay times such as DELAY-1, DELAY-2 and and normalization delay in the AS/RS fetching operation.

The total processing times of six machine centers were dependent upon what types of part families were processed frequently by the machine center cell under a decision rule set. Part family 6 had the longest processing time, and part family 4 had the shortest processing time. Processing times did not include any failure times or idle times of each machine center.

The total processing times of the turning cell were dependent on processing times of parts on lathe 1, lathe 2, the washing station, the robot, and number of parts processed by the turning cell. Again, this time factor did not include any failure times of the robot or idle times of lathe 1, lathe 2, the washing station, and the robot. The turning cell processing time was 20 minutes as presented in Chapter 5.

Table 7-1 presents the total fetch time, total processing time on the machine center cell, and total processing time on the turning cell for every decision rule. All times are the real time values regenerated from the model times using the time scaling factor for a decision rule set. Table 7-2 presents the effectivities of the AS/RS cart, the machine center cell and the turning cell for each decision rule set.

The actual system effectivity was an average effectivity of all major system components. It is presented for each decision rule set

Table 7-1. Total processing time values for major components

| Set | Decision rule set | A (hrs.) | B (hrs.) | C (hrs.) |
|---|---|---|---|---|
| 1 | RANDOM/RANDOM | 67.7502 | 516.8329 | 110.0728 |
| 2 | RANDOM/FMFS | 67.4764 | 509.2157 | 109.5389 |
| 3 | RANDOM/NINQ | 69.4161 | 537.5287 | 110.0084 |
| 4 | RANDOM/WINQ | 66.3607 | 543.6296 | 110.4246 |
| 5 | FSFS/RANDOM | 66.0885 | 522.0355 | 109.9024 |
| 6 | FSFS/FMFS | 66.7514 | 555.6948 | 108.7515 |
| 7 | FSFS/NINQ | 66.3900 | 556.1841 | 108.6514 |
| 8 | FSFS/WINQ | 65.3854 | 543.6755 | 109.4599 |
| 9 | SPT/RANDOM | 66.5869 | 495.8197 | 111.4879 |
| 10 | SPT/FMFS | 64.3874 | 504.1696 | 109.6098 |
| 11 | SPT/NINQ | 68.8166 | 452.0172 | 108.8305 |
| 12 | SPT/WINQ | 66.8151 | 434.0662 | 109.1642 |
| 13 | DDATE/RANDOM | 66.7356 | 487.3686 | 109.9631 |
| 14 | DDATE/FMFS | 65.1759 | 505.0123 | 108.8162 |
| 15 | DDATE/NINQ | 68.3255 | 447.0199 | 109.4221 |
| 16 | DDATE/WINQ | 66.3686 | 452.7475 | 109.3484 |
| 17 | SLACK/RANDOM | 63.6124 | 463.4709 | 110.1308 |
| 18 | SLACK/FMFS | 64.6141 | 502.7152 | 110.5338 |
| 19 | SLACK/NINQ | 66.2541 | 470.3096 | 108.7829 |
| 20 | SLACK/WINQ | 65.4308 | 451.8197 | 108.9856 |
| 21 | S/PT/RANDOM | 65.3336 | 487.0797 | 109.9882 |
| 22 | S/PT/FMFS | 64.6650 | 499.1725 | 108.3235 |
| 23 | S/PT/NINQ | 67.4887 | 478.4986 | 110.6258 |
| 24 | S/PT/WINQ | 64.4943 | 488.0472 | 110.5698 |
| 25 | VALUE/RANDOM | 65.7384 | 536.0550 | 109.4459 |
| 26 | VALUE/FMFS | 64.7591 | 505.4698 | 108.6563 |
| 27 | VALUE/NINQ | 65.2997 | 552.9937 | 109.2751 |
| 28 | VALUE/WINQ | 63.4627 | 563.7280 | 108.7295 |

A = total fetch time for the AS/RS cart

B = total processing time for the machine center cell

C = total processing time for the turning cell

Actual system effectivity
= (A + B/6 + C)/(simulation run time * 3)
Simulation run time = 140 hours

Table 7-2. Effecivity for major components (effectivity:rank)

| Set | Decision rule set | A | B | C | D |
|---|---|---|---|---|---|
| 1 | RANDOM/RANDOM | 0.4839:4 | 0.6153:10 | 0.7862:7 | 0.6285:9 |
| 2 | RANDOM/FMFS | 0.4820:6 | 0.6062:11 | 0.7824:13 | 0.6235:11 |
| 3 | RANDOM/NINQ | 0.4958:1 | 0.6399:7 | 0.7858:8 | 0.6405:1 |
| 4 | RANDOM/WINQ | 0.4740:12 | 0.6472:5 | 0.7887:5 | 0.6366:4 |
| 5 | FSFS/RANDOM | 0.4721:15 | 0.6215:9 | 0.7850:11 | 0.6262:10 |
| 6 | FSFS/FMFS | 0.4768:8 | 0.6615:3 | 0.7768:24 | 0.6384:2 |
| 7 | FSFS/NINQ | 0.4738:13 | 0.6621:2 | 0.7761:26 | 0.6373:3 |
| 8 | FSFS/WINQ | 0.4670:18 | 0.6472:5 | 0.7819:14 | 0.6320:7 |
| 9 | SPT/RANDOM | 0.4756:10 | 0.5903:17 | 0.7963:1 | 0.6207:12 |
| 10 | SPT/FMFS | 0.4599:26 | 0.6002:14 | 0.7829:12 | 0.6143:15 |
| 11 | SPT/NINQ | 0.4915:2 | 0.5381:26 | 0.7774:21 | 0.6023:23 |
| 12 | SPT/WINQ | 0.4773:7 | 0.5167:28 | 0.7797:19 | 0.5912:28 |
| 13 | DDATE/RANDOM | 0.4767:9 | 0.5802:19 | 0.7855:10 | 0.6141:16 |
| 14 | DDATE/FMFS | 0.4655:21 | 0.6012:13 | 0.7773:22 | 0.6147:14 |
| 15 | DDATE/NINQ | 0.4880:3 | 0.5322:27 | 0.7816:16 | 0.6006:24 |
| 16 | DDATE/WINQ | 0.4741:11 | 0.5390:24 | 0.7811:17 | 0.5981:25 |
| 17 | SLACK/RANDOM | 0.4544:27 | 0.5518:23 | 0.7866:6 | 0.5976:26 |
| 18 | SLACK/FMFS | 0.4615:24 | 0.5985:15 | 0.7895:4 | 0.6165:13 |
| 19 | SLACK/NINQ | 0.4732:14 | 0.5599:22 | 0.7770:23 | 0.6034:22 |
| 20 | SLACK/WINQ | 0.4674:17 | 0.5379:25 | 0.7785:20 | 0.5946:27 |
| 21 | S/PT/RANDOM | 0.4667:19 | 0.5799:20 | 0.7856:9 | 0.6107:19 |
| 22 | S/PT/FMFS | 0.4619:22 | 0.5943:16 | 0.7737:28 | 0.6100:21 |
| 23 | S/PT/NINQ | 0.4821:5 | 0.5696:21 | 0.7902:2 | 0.6140:17 |
| 24 | S/PT/WINQ | 0.4607:25 | 0.5810:18 | 0.7898:3 | 0.6105:20 |
| 25 | VALUE/RANDOM | 0.4696:16 | 0.6382:8 | 0.7818:15 | 0.6298:8 |
| 26 | VALUE/FMFS | 0.4626:23 | 0.6017:12 | 0.7761:26 | 0.6135:18 |
| 27 | VALUE/NINQ | 0.4664:20 | 0.6583:4 | 0.7805:18 | 0.6351:5 |
| 28 | VALUE/WINQ | 0.4533:28 | 0.6711:1 | 0.7766:25 | 0.6337:6 |

A = effectivity of the AS/RS cart

B = effectivity of the machine center cell

C = effectivity of the turning cell

D = actual system effectivity

in Table 7-2. Recall that the simulation run time was 140 hours in real time. Each decision rule set has a relative rank by effectivity. Table 7-3 presents the relative system effectivity and its relative rank for each decision rule set. The relative system effectivity was determined by the actual system effectivity divided by the theoretical system effectivity. The relative system effectivity was the maximum system utilization rate possible with failures of major system components.

The RANDOM/NINQ rule set had the highest value in both the actual system effectivity and relative system effectivity. The SPT/WINQ rule set had the lowest values for both effectivity criteria.

3. Total traveling times for parts

The total traveling time for parts was defined as the sum of total model fetch time from/to a storage area and the total model route time to either a machine center or the turning cell. The total model fetch time was determined by total number of fetches multiplied by model fetch time from each of eight storage areas. The total model route time was determined by both total number of routes to any of six machine centers or the turning cell and model route time for each route path. This time factor did not include any failure times, idle times or delay times in either the AS/RS cell and the AGVS.

Tables 7-4a and 7-4b present the total number of fetches from each storage area and the total number of routes to either a machine center or the turning cell. Table 7-5 presents the total fetch times

Table 7-3. Relative system effectivity and its rank

| Set | Decision rule set | Relative system effectivity | Rank |
|---|---|---|---|
| 1 | RANDOM/RANDOM | 0.8351 | 9 |
| 2 | RANDOM/FMFS | 0.8285 | 11 |
| 3 | RANDOM/NINQ | 0.8510 | 1 |
| 4 | RANDOM/WINQ | 0.8459 | 4 |
| 5 | FSFS/RANDOM | 0.8320 | 10 |
| 6 | FSFS/FMFS | 0.8483 | 2 |
| 7 | FSFS/NINQ | 0.8468 | 3 |
| 8 | FSFS/WINQ | 0.8398 | 7 |
| 9 | SPT/RANDOM | 0.8247 | 12 |
| 10 | SPT/FMFS | 0.8162 | 15 |
| 11 | SPT/NINQ | 0.8003 | 23 |
| 12 | SPT/WINQ | 0.7855 | 28 |
| 13 | DDATE/RANDOM | 0.8160 | 16 |
| 14 | DDATE/FMFS | 0.8168 | 14 |
| 15 | DDATE/NINQ | 0.7980 | 24 |
| 16 | DDATE/WINQ | 0.7941 | 25 |
| 17 | SLACK/RANDOM | 0.7940 | 26 |
| 18 | SLACK/FMFS | 0.8192 | 13 |
| 19 | SLACK/NINQ | 0.8018 | 22 |
| 20 | SLACK/WINQ | 0.7901 | 27 |
| 21 | S/PT/RANDOM | 0.8115 | 19 |
| 22 | S/PT/FMFS | 0.8105 | 21 |
| 23 | S/PT/NINQ | 0.8158 | 17 |
| 24 | S/PT/WINQ | 0.8112 | 20 |
| 25 | VALUE/RANDOM | 0.8368 | 8 |
| 26 | VALUE/FMFS | 0.8152 | 18 |
| 27 | VALUE/NINQ | 0.8439 | 5 |
| 28 | VALUE/WINQ | 0.8420 | 6 |

Theoretical system effectivity = 0.7526

$$\text{Relative system effectivity} = \frac{\text{Actual system effectivity}}{\text{Theoretical system effectivity}}$$

Table 7-4a. Total number of fetches

| Set | Decision rule set | Storage area 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | RANDOM/RANDOM | 101 | 96 | 89 | 106 | 103 | 102 | 93 | 259 |
| 2 | RANDOM/FMFS | 99 | 96 | 101 | 96 | 98 | 96 | 101 | 255 |
| 3 | RANDOM/NINQ | 91 | 105 | 89 | 99 | 96 | 99 | 118 | 257 |
| 4 | RANDOM/WINQ | 107 | 104 | 100 | 107 | 97 | 101 | 96 | 257 |
| 5 | FSFS/RANDOM | 129 | 133 | 118 | 122 | 105 | 57 | 41 | 250 |
| 6 | FSFS/FMFS | 113 | 106 | 101 | 105 | 106 | 95 | 82 | 248 |
| 7 | FSFS/NINQ | 162 | 150 | 128 | 130 | 62 | 52 | 40 | 248 |
| 8 | FSFS/WINQ | 162 | 145 | 117 | 122 | 99 | 41 | 23 | 255 |
| 9 | SPT/RANDOM | 146 | 111 | 84 | 145 | 133 | 54 | 27 | 271 |
| 10 | SPT/FMFS | 106 | 95 | 96 | 106 | 95 | 91 | 68 | 257 |
| 11 | SPT/NINQ | 217 | 49 | 28 | 241 | 194 | 30 | 10 | 251 |
| 12 | SPT/WINQ | 220 | 43 | 40 | 245 | 194 | 13 | 1 | 249 |
| 13 | DDATE/RANDOM | 84 | 79 | 80 | 149 | 138 | 79 | 87 | 262 |
| 14 | DDATE/FMFS | 102 | 92 | 95 | 112 | 97 | 88 | 96 | 248 |
| 15 | DDATE/NINQ | 79 | 71 | 71 | 204 | 174 | 60 | 77 | 253 |
| 16 | DDATE/WINQ | 92 | 72 | 67 | 182 | 162 | 65 | 79 | 251 |
| 17 | SLACK/RANDOM | 90 | 76 | 83 | 141 | 126 | 82 | 83 | 257 |
| 18 | SLACK/FMFS | 99 | 102 | 102 | 106 | 102 | 87 | 88 | 265 |
| 19 | SLACK/NINQ | 87 | 83 | 72 | 184 | 154 | 72 | 73 | 246 |
| 20 | SLACK/WINQ | 77 | 70 | 68 | 193 | 166 | 61 | 79 | 239 |
| 21 | S/PT/RANDOM | 103 | 89 | 86 | 109 | 105 | 86 | 99 | 264 |
| 22 | S/PT/FMFS | 94 | 97 | 97 | 99 | 101 | 92 | 93 | 241 |
| 23 | S/PT/NINQ | 100 | 92 | 93 | 124 | 107 | 94 | 90 | 260 |
| 24 | S/PT/WINQ | 101 | 95 | 91 | 120 | 103 | 95 | 99 | 260 |
| 25 | VALUE/RANDOM | 104 | 109 | 103 | 96 | 90 | 83 | 83 | 250 |
| 26 | VALUE/FMFS | 97 | 97 | 95 | 93 | 92 | 84 | 96 | 249 |
| 27 | VALUE/NINQ | 136 | 142 | 140 | 128 | 61 | 53 | 43 | 245 |
| 28 | VALUE/WINQ | 146 | 134 | 130 | 137 | 62 | 50 | 36 | 246 |

Storage area 1 was the nearest storage area from the AS/RS cart's starting position. Storage area 8 was the most distant storage area. However, storage area 7 was the most distant storage area to which the AS/RS cart could access under a part selection rule.

Table 7-4b. Total number of routes

| Set | Decision rule set | Machine center 1 | 2 | 3 | 4 | 5 | 6 | Turning cell |
|---|---|---|---|---|---|---|---|---|
| 1 | RANDOM/RANDOM | 117 | 128 | 115 | 124 | 103 | 97 | 265 |
| 2 | RANDOM/FMFS | 122 | 131 | 98 | 114 | 125 | 90 | 262 |
| 3 | RANDOM/NINQ | 107 | 124 | 119 | 124 | 106 | 115 | 259 |
| 4 | RANDOM/WINQ | 120 | 123 | 115 | 116 | 122 | 110 | 263 |
| 5 | FSFS/RANDOM | 112 | 116 | 118 | 121 | 113 | 119 | 256 |
| 6 | FSFS/FMFS | 132 | 116 | 110 | 134 | 110 | 98 | 250 |
| 7 | FSFS/NINQ | 132 | 135 | 118 | 117 | 115 | 103 | 252 |
| 8 | FSFS/WINQ | 113 | 115 | 115 | 143 | 102 | 119 | 257 |
| 9 | SPT/RANDOM | 109 | 125 | 106 | 126 | 117 | 114 | 274 |
| 10 | SPT/FMFS | 131 | 133 | 103 | 112 | 96 | 81 | 258 |
| 11 | SPT/NINQ | 149 | 148 | 116 | 128 | 126 | 98 | 255 |
| 12 | SPT/WINQ | 153 | 136 | 113 | 131 | 111 | 109 | 252 |
| 13 | DDATE/RANDOM | 117 | 115 | 122 | 120 | 110 | 108 | 266 |
| 14 | DDATE/FMFS | 137 | 127 | 107 | 123 | 97 | 84 | 255 |
| 15 | DDATE/NINQ | 149 | 138 | 112 | 131 | 105 | 97 | 257 |
| 16 | DDATE/WINQ | 136 | 125 | 115 | 133 | 103 | 103 | 255 |
| 17 | SLACK/RANDOM | 118 | 115 | 109 | 120 | 111 | 102 | 263 |
| 18 | SLACK/FMFS | 122 | 128 | 120 | 126 | 105 | 80 | 270 |
| 19 | SLACK/NINQ | 124 | 126 | 127 | 125 | 113 | 105 | 251 |
| 20 | SLACK/WINQ | 130 | 119 | 116 | 127 | 113 | 103 | 245 |
| 21 | S/PT/RANDOM | 126 | 117 | 106 | 121 | 108 | 97 | 266 |
| 22 | S/PT/FMFS | 129 | 121 | 97 | 114 | 107 | 98 | 248 |
| 23 | S/PT/NINQ | 139 | 117 | 125 | 120 | 98 | 94 | 267 |
| 24 | S/PT/WINQ | 135 | 123 | 114 | 118 | 95 | 114 | 265 |
| 25 | VALUE/RANDOM | 127 | 100 | 107 | 121 | 111 | 98 | 254 |
| 26 | VALUE/FMFS | 110 | 122 | 109 | 104 | 101 | 102 | 255 |
| 27 | VALUE/NINQ | 138 | 115 | 111 | 103 | 114 | 115 | 252 |
| 28 | VALUE/WINQ | 124 | 121 | 121 | 110 | 107 | 106 | 252 |

The first operation of parts 1, 3 and 5 was processed by the turning cell. The first operation for the rest of parts was processed by a machine center. Semifinished parts were routed to a machine center. Machine center 1 was the nearest center from the AS/RS cell. Machine center 6 was the most distant center.

Table 7-5. Total traveling time

| Set | Decision rule set | A (hrs.:rank) | B (hrs.:rank) | C (hrs.:rank) |
|---|---|---|---|---|
| 1 | RANDOM/RANDOM | 67.7502:25 | 44.1543:28 | 111.9045:28 |
| 2 | RANDOM/FMFS | 67.4764:23 | 38.4437:19 | 105.9201:23 |
| 3 | RANDOM/NINQ | 69.4161:28 | 38.5926:21 | 108.0087:26 |
| 4 | RANDOM/WINQ | 66.3607:17 | 38.3823:18 | 104.7430:18 |
| 5 | FSFS/RANDOM | 66.0885:14 | 38.7350:23 | 104.8235:19 |
| 6 | FSFS/FMFS | 66.7514:21 | 38.6617:22 | 105.4131:22 |
| 7 | FSFS/NINQ | 66.3300:16 | 39.0400:25 | 105.3700:21 |
| 8 | FSFS/WINQ | 65.3854:11 | 38.2284:17 | 103.6138:13 |
| 9 | SPT/RANDOM | 66.5869:19 | 38.4809:20 | 105.0678:20 |
| 10 | SPT/FMFS | 64.3874:3 | 36.5223:3 | 100.9097:3 |
| 11 | SPT/NINQ | 68.8166:27 | 40.5956:27 | 109.4122:27 |
| 12 | SPT/WINQ | 66.8151:22 | 39.4585:26 | 106.2736:24 |
| 13 | DDATE/RANDOM | 66.7356:20 | 37.8516:16 | 104.5872:16 |
| 14 | DDATE/FMFS | 65.1759:8 | 36.8512:7 | 102.0271:8 |
| 15 | DDATE/NINQ | 68.3255:26 | 38.8257:24 | 107.1512:25 |
| 16 | DDATE/WINQ | 66.3686:18 | 37.6487:13 | 104.0173:14 |
| 17 | SLACK/RANDOM | 63.6124:2 | 36.4172:2 | 100.0296:1 |
| 18 | SLACK/FMFS | 64.6141:5 | 36.9097:8 | 101.5238:7 |
| 19 | SLACK/NINQ | 66.2541:15 | 37.8406:15 | 104.0947:15 |
| 20 | SLACK/WINQ | 65.4308:12 | 37.3166:12 | 102.7474:11 |
| 21 | S/PT/RANDOM | 65.3336:10 | 36.7635:5 | 102.0971:9 |
| 22 | S/PT/FMFS | 64.6650:6 | 36.2916:1 | 100.9566:4 |
| 23 | S/PT/NINQ | 67.4887:24 | 37.1001:11 | 104.5888:17 |
| 24 | S/PT/WINQ | 64.4943:4 | 36.8022:6 | 101.2965:6 |
| 25 | VALUE/RANDOM | 65.7384:13 | 36.9957:10 | 102.7341:10 |
| 26 | VALUE/FMFS | 64.7591:7 | 36.5352:4 | 101.2943:5 |
| 27 | VALUE/NINQ | 65.2997:9 | 37.7401:14 | 103.0398:12 |
| 28 | VALUE/WINQ | 63.4627:1 | 36.9150:9 | 100.3777:2 |

A = total fetch time in real time

B = total route time in real time

C = total traveling time (= A + B)

and total route times for each decision rule set. The sum of both totals is the total traveling time for each decision rule set. All time values are the real time values regenerated from the model times using a time scaling factor for each decision rule set. Each decision rule set is assigned a relative rank for each of the total time values.

Table 7-6 presents average traveling time per part which was determined by the total traveling time in real time divided by the total number of fetches under a decision rule set. Each decision rule set is assignsd a relative rank in terms of the average traveling time per part.

The total traveling time would be minimized if the AS/RS cart traveled to storage area 1 each time and every fetched part was routed to the turning cell. However, parts were not always available in storage area 1. Also, the turning cell was restrictsd by a maximum queue length of five parts. Further, some parts were initially routed directly to one of the machining centers.

4. Actual production output

The actual production output was defined as the actual number of parts produced by the FMS model under a decision rule set. As presented in Chapter 5, the last operation of each part family was processed by one of six machine centers. This means that parts processed by a machine center were counted as the actual production output.

The actual production output under a decision rule set was affected by both the failures and idle time of major system compo-

Table 7-6. Average traveling time per part and its rank

| Set | Decision rule set | Total number of fetches | Average traveling time per part (hrs.) | Rank |
|---|---|---|---|---|
| 1 | RANDOM/RANDOM | 949 | 0.1179 | 28 |
| 2 | RANDOM/FMFS | 942 | 0.1124 | 26 |
| 3 | RANDOM/NINQ | 954 | 0.1132 | 27 |
| 4 | RANDOM/WINQ | 969 | 0.1081 | 11 |
| 5 | FSFS/RANDOM | 955 | 0.1098 | 20 |
| 6 | FSFS/FMFS | 950 | 0.1110 | 23 |
| 7 | FSFS/NINQ | 972 | 0.1084 | 14 |
| 8 | FSFS/WINQ | 964 | 0.1075 | 9 |
| 9 | SPT/RANDOM | 971 | 0.1082 | 12 |
| 10 | SPT/FMFS | 914 | 0.1104 | 21 |
| 11 | SPT/NINQ | 1020 | 0.1073 | 8 |
| 12 | SPT/WINQ | 1005 | 0.1057 | 2 |
| 13 | DDATE/RANDOM | 958 | 0.1092 | 18 |
| 14 | DDATE/FMFS | 930 | 0.1097 | 19 |
| 15 | DDATE/NINQ | 989 | 0.1083 | 13 |
| 16 | DDATE/WINQ | 970 | 0.1072 | 6 |
| 17 | SLACK/RANDOM | 938 | 0.1066 | 3 |
| 18 | SLACK/FMFS | 951 | 0.1068 | 5 |
| 19 | SLACK/NINQ | 971 | 0.1072 | 6 |
| 20 | SLACK/WINQ | 953 | 0.1078 | 10 |
| 21 | S/PT/RANDOM | 941 | 0.1085 | 15 |
| 22 | S/PT/FMFS | 914 | 0.1105 | 22 |
| 23 | S/PT/NINQ | 960 | 0.1089 | 17 |
| 24 | S/PT/WINQ | 964 | 0.1051 | 1 |
| 25 | VALUE/RANDOM | 918 | 0.1119 | 24 |
| 26 | VALUE/FMFS | 903 | 0.1122 | 25 |
| 27 | VALUE/NINQ | 948 | 0.1087 | 16 |
| 28 | VALUE/WINQ | 941 | 0.1067 | 4 |

$$\text{Average traveling time} = \frac{\text{Total traveling time}}{\text{Total number of fetches}}$$

nents. As presented in Chapter 5, the AS/RS fetching capacity was 1.8574 parts per minute. The production capacity of the machine center cell and the turning cell was 1.387 parts per minute. Therefore, the AS/RS cell could provide enough parts to either of the workcenters.

The achievement rate was determined by the actual production output divided by total number fetches in Chapter 5. This rate represents a measure of the productivity of the FMS model under a decision rule set.

Table 7-7 presents total number of fetches, the actual production output and the achievement rate under a decision rule set. Each decision rule set is assigned a relative rank in each category.

If the more parts were fetched from storage areas under decision rule set, the model also manufactured more parts from the machine center cell. The achievement rate for a decision rule set was high if the actual production output was high.

5. Manufacturing throughput time

The manufacturing throughput time of a part was determined by the difference between arrival time and process completion time. As presented in Chapter 5, the arrival time for each of the thirty-five parts stored on seven storage areas was zero when the simulation started. A fetched part was assigned a specific arrival time when the part returned to its original storage area as a raw material from the return queue. That is, the arrival time of the processed part was determined by the sum of completion time and return time to its

Table 7-7. Actual production output and its rank

| Set | Decision rule set | Total number of fetches (fetches:rank) | Actual production output (output:rank) | Achievement rate (rate:rank) |
|---|---|---|---|---|
| 1 | RANDOM/RANDOM | 949:18 | 658:19 | 0.6993:15 |
| 2 | RANDOM/FMFS | 942:20 | 655:20 | 0.6953:20 |
| 3 | RANDOM/NINQ | 954:14 | 666:16 | 0.6981:16 |
| 4 | RANDOM/WINQ | 969:8 | 680:8 | 0.7018:14 |
| 5 | FSFS/RANDOM | 955:13 | 673:10 | 0.7047:10 |
| 6 | FSFS/FMFS | 950:17 | 671:12 | 0.7063:9 |
| 7 | FSFS/NINQ | 972:4 | 692:7 | 0.7119:7 |
| 8 | FSFS/WINQ | 964:9 | 677:9 | 0.7023:13 |
| 9 | SPT/RANDOM | 971:5 | 669:14 | 0.6890:24 |
| 10 | SPT/FMFS | 914:26 | 626:27 | 0.6849:28 |
| 11 | SPT/NINQ | 1020:1 | 739:1 | 0.7245:4 |
| 12 | SPT/WINQ | 1005:2 | 731:2 | 0.7274:2 |
| 13 | DDATE/RANDOM | 958:12 | 664:17 | 0.6931:22 |
| 14 | DDATE/FMFS | 930:24 | 649:22 | 0.6979:17 |
| 15 | DDATE/NINQ | 989:3 | 718:3 | 0.7260:3 |
| 16 | DDATE/WINQ | 970:7 | 694:5 | 0.7155:5 |
| 17 | SLACK/RANDOM | 938:23 | 649:22 | 0.6919:23 |
| 18 | SLACK/FMFS | 951:16 | 655:20 | 0.6888:25 |
| 19 | SLACK/NINQ | 971:5 | 693:6 | 0.7137:6 |
| 20 | SLACK/WINQ | 953:15 | 699:4 | 0.7335:1 |
| 21 | S/PT/RANDOM | 941:21 | 647:24 | 0.6876:27 |
| 22 | S/PT/FMFS | 914:26 | 642:25 | 0.7024:12 |
| 23 | S/PT/NINQ | 960:11 | 669:14 | 0.6969:19 |
| 24 | S/PT/WINQ | 964:9 | 672:11 | 0.6971:18 |
| 25 | VALUE/RANDOM | 918:25 | 637:26 | 0.6939:21 |
| 26 | VALUE/FMFS | 903:28 | 622:28 | 0.6888:25 |
| 27 | VALUE/NINQ | 948:19 | 670:13 | 0.7068:8 |
| 28 | VALUE/WINQ | 941:21 | 663:18 | 0.7046:11 |

$$\text{Achievement rate} = \frac{\text{Actual production output}}{\text{Total number of fetches}}$$

original storage area.

The completion time was the time at which the return queue released a processed part to the second lifting ramp. The return time included a part's traveling time to its original storage area and the second lifting ramp's operation time. Table 7-8 presents the return time to each seven storage areas. Storage area 1 was the most distant storage area from the return queue.

Table 7-8. Return time to a atorage area

| Storage area | Return time (min.) |
|---|---|
| 1 | 0.2501 |
| 2 | 0.2155 |
| 3 | 0.2004 |
| 4 | 0.1886 |
| 5 | 0.1842 |
| 6 | 0.1761 |
| 7 | 0.1673 |

The throughput time of a part included all failure times and idle times of major system components, and delays in every fetch. A part experienced idle time when the following situations occurred:

- A part waited at a storage area as a raw material;
- One of parts 1, 3 or 5 waited in the turning cell input queue;
- One of parts 1, 3 or 5 waited in the turning cell finished queue;
- A part waited in a machine center waiting line;
- A processed part waited in the return queue.

If a decision rule had less idle time than other decision rule sets, the rule set would have lower throughput times. The maximum queue length was a major factor in determining the idle times under a decision rule set. This means that the model must generate available spaces more frequently for either the machine center cell or the turning cell to reduce the throughput time of a part under a decision rule set. Either a machine center or the turning cell was easily full with five parts (maximum queue length) when the following situations occurred:

- The AS/RS cart failed;
- One of six machine centers failed;
- The robot in the turning cell failed;
- A machine center queue had parts with long processing times.

Average throughput time per part was determined by total throughput times divided by the actual production output under a decision rule set. Table 7-9 presents the total throughput times and the average throughput time per part. All throughput time values are the real time values regenerated from the model times using the time scaling factor for a decision rule set. Each decision rule set is assigned a relative rank in each category.

6. Work-in-process inventory

As described in Chapter 5, there are two traditional ways to measure the work-in-process inventory:

- Work Remaining - The sum of the processing times of all operations not yet completed or in process for all parts in both the machine center cell and the turning cell at the end of the simulation for a decision rule set;

- Imminent Operation Work Content - The sum of the processing times of the particular operations for those parts that were waiting in each queue of six machine centers or the turning cell input queue at the end of the simulation for a decision rule set.

As an additional measure, total waiting time was used. This measure was included in the total idle time of the total throughput time under a decision rule set. The total waiting time was defined as the sum of waiting times of all processed parts in the machine

Table 7-9. Throughput time and its rank

| Set | Decision rule set | Total throughput time (hrs.:rank) | Average throughput time (hrs.:rank) |
|---|---|---|---|
| 1 | RANDOM/RANDOM | 4704.9684:9 | 7.1504:18 |
| 2 | RANDOM/FMFS | 4744.1880:27 | 7.2430:21 |
| 3 | RANDOM/NINQ | 4695.7622:4 | 7.0507:13 |
| 4 | RANDOM/WINQ | 4722.2048:15 | 6.9444:9 |
| 5 | FSFS/RANDOM | 4697.5972:5 | 6.9801:10 |
| 6 | FSFS/FMFS | 4700.3354:6 | 7.0167:11 |
| 7 | FSFS/NINQ | 4716.5522:12 | 6.8158:6 |
| 8 | FSFS/WINQ | 4695.5417:3 | 6.9358:8 |
| 9 | SPT/RANDOM | 4730.6549:22 | 7.0712:14 |
| 10 | SPT/FMFS | 4704.0742:7 | 7.5145:27 |
| 11 | SPT/NINQ | 4611.4026:2 | 6.2401:2 |
| 12 | SPT/WINQ | 4051.8839:1 | 5.5429:1 |
| 13 | DDATE/RANDOM | 4729.6523:20 | 7.1230:17 |
| 14 | DDATE/FMFS | 4737.4669:24 | 7.2996:24 |
| 15 | DDATE/NINQ | 4724.6045:16 | 6.5802:3 |
| 16 | DDATE/WINQ | 4715.3661:11 | 6.7945:5 |
| 17 | SLACK/RANDOM | 4729.9889:21 | 7.2881:23 |
| 18 | SLACK/FMFS | 4721.5081:19 | 7.2176:20 |
| 19 | SLACK/NINQ | 4730.9574:23 | 6.8268:7 |
| 20 | SLACK/WINQ | 4721.7816:14 | 6.7551:4 |
| 21 | S/PT/RANDOM | 4704.5690:8 | 7.2714:22 |
| 22 | S/PT/FMFS | 4716.7887:13 | 7.3470:25 |
| 23 | S/PT/NINQ | 4754.1233:28 | 7.1063:16 |
| 24 | S/PT/WINQ | 4726.8576:17 | 7.0340:12 |
| 25 | VALUE/RANDOM | 4705.4997:10 | 7.3870:26 |
| 26 | VALUE/FMFS | 4727.1372:18 | 7.5999:28 |
| 27 | VALUE/NINQ | 4743.8633:26 | 7.0804:15 |
| 28 | VALUE/WINQ | 4741.9019:25 | 7.1522:19 |

$$\text{Average throughput time} = \frac{\text{Total throughput time}}{\text{Actual production output}}$$

center queues. Every new arrival joined the machine center queues and waited until previous arrivals were released from the machine centers. The waiting time for a part was thus the difference between a part's arrival time to a machine center and the machine center's start time to process the part. The total waiting time included the failure times and idle time of major components, and delays in every fetch. Average waiting time per part was determined by the total waiting time divided by the actual production output under a decision rule set.

Table 7-10 presents both the work remaining and the imminent operation work content for every decision rule set. Both measures are the real time values regenerated from the model times using the time scaling factor for a decision rule set. Each decision rule set is assigned a relative rank in each category. Table 7-11 presents both the total waiting times and the average waiting time per part. Both measures are the real time values regenerated from the model times using a time scaling factor for a decision rule set. Each decision rule set is again assigned a relative rank in each category.

7. Production lateness

The total production lateness was defined as the sum of differences between the actual time at which a part was completed and the time at which completion was desired (due-date) under a decision rule set. The actual completion time was determined by the sum of arrival time, processing time of a part, the failure times/idle times of major components, and delays in every fetch.

Table 7-10. Work-in-process inventory and its rank

| Set | Decision rule set | Work remaining (hrs.:rank) | Imminent operation work content (hrs.:rank) |
|---|---|---|---|
| 1 | RANDOM/RANDOM | 27.5600:19 | 10.8666:28 |
| 2 | RANDOM/FMFS | 24.0700:7 | 6.8233:10 |
| 3 | RANDOM/NINQ | 27.3701:16 | 9.3134:24 |
| 4 | RANDOM/WINQ | 28.0468:23 | 6.8267:11 |
| 5 | FSFS/RANDOM | 28.6101:27 | 9.0100:22 |
| 6 | FSFS/FMFS | 23.9666:5 | 5.9466:4 |
| 7 | FSFS/NINQ | 27.0801:14 | 10.6167:27 |
| 8 | FSFS/WINQ | 28.2233:25 | 8.9900:21 |
| 9 | SPT/RANDOM | 24.8166:8 | 6.1433:6 |
| 10 | SPT/FMFS | 27.5933:20 | 10.2833:26 |
| 11 | SPT/NINQ | 27.8567:22 | 6.1433:6 |
| 12 | SPT/WINQ | 16.9668:3 | 6.5300:8 |
| 13 | DDATE/RANDOM | 28.4167:26 | 9.0367:23 |
| 14 | DDATE/FMFS | 27.4101:17 | 7.8434:17 |
| 15 | DDATE/NINQ | 16.3201:2 | 8.7400:19 |
| 16 | DDATE/WINQ | 19.9967:4 | 7.7700:16 |
| 17 | SLACK/RANDOM | 29.0167:28 | 5.4100:1 |
| 18 | SLACK/FMFS | 26.6434:12 | 7.1334:12 |
| 19 | SLACK/NINQ | 27.8100:21 | 8.8134:20 |
| 20 | SLACK/WINQ | 11.2500:1 | 5.6767:2 |
| 21 | S/PT/RANDOM | 28.1800:24 | 7.5467:15 |
| 22 | S/PT/FMFS | 26.6034:11 | 6.7267:9 |
| 23 | S/PT/NINQ | 27.4235:18 | 9.5561:25 |
| 24 | S/PT/WINQ | 23.9933:6 | 7.1400:13 |
| 25 | VALUE/RANDOM | 26.1733:10 | 7.2866:14 |
| 26 | VALUE/FMFS | 25.1533:9 | 7.8667:18 |
| 27 | VALUE/NINQ | 27.1234:15 | 5.8934:3 |
| 28 | VALUE/WINQ | 26.7099:13 | 5.9933:5 |

Work remaining = The sum of the processing times of all operations not yet completed or in process for all parts in the workcenters.

Imminent operation work content = The sum of the processing times of the particular operations for which parts were waiting in each queue of the workcenters.

Table 7-11. Waiting time and its rank

| Set | Decision rule set | Total waiting time (hrs.:rank) | Average waiting time (hrs.:rank) |
|---|---|---|---|
| 1 | RANDOM/RANDOM | 2554.5286:20 | 3.8823:20 |
| 2 | RANDOM/FMFS | 2801.5895:26 | 4.2772:24 |
| 3 | RANDOM/NINQ | 1632.3811:9 | 2.4510:9 |
| 4 | RANDOM/WINQ | 1727.4392:10 | 2.5404:10 |
| 5 | FSFS/RANDOM | 2373.7681:19 | 3.5272:19 |
| 6 | FSFS/FMFS | 2895.1471:27 | 4.3147:26 |
| 7 | FSFS/NINQ | 2016.5904:16 | 2.9142:13 |
| 8 | FSFS/WINQ | 1956.4216:14 | 2.8898:11 |
| 9 | SPT/RANDOM | 2021.3746:17 | 3.0215:17 |
| 10 | SPT/FMFS | 2749.8514:23 | 4.3927:27 |
| 11 | SPT/NINQ | 848.4780:5 | 1.1482:4 |
| 12 | SPT/WINQ | 690.3297:3 | 0.9444:3 |
| 13 | DDATE/RANDOM | 1958.6166:15 | 2.9497:16 |
| 14 | DDATE/FMFS | 2752.0157:24 | 4.2404:22 |
| 15 | DDATE/NINQ | 645.5550:2 | 0.8991:2 |
| 16 | DDATE/WINQ | 848.4172:4 | 1.2225:5 |
| 17 | SLACK/RANDOM | 1895.3455:11 | 2.9204:14 |
| 18 | SLACK/FMFS | 2699.3833:21 | 4.1212:21 |
| 19 | SLACK/NINQ | 1169.9402:7 | 1.6882:7 |
| 20 | SLACK/WINQ | 568.7459:1 | 0.8137:1 |
| 21 | S/PT/RANDOM | 2059.3666:18 | 3.1829:18 |
| 22 | S/PT/FMFS | 2766.8777:25 | 4.3098:25 |
| 23 | S/PT/NINQ | 863.8741:6 | 1.2913:6 |
| 24 | S/PT/WINQ | 1220.4032:8 | 1.8161:8 |
| 25 | VALUE/RANDOM | 2723.2689:22 | 4.2751:23 |
| 26 | VALUE/FMFS | 2947.9559:28 | 4.7395:28 |
| 27 | VALUE/NINQ | 1945.9020:13 | 2.9043:12 |
| 28 | VALUE/WINQ | 1938.9364:12 | 2.9245:15 |

$$\text{Average waiting time} = \frac{\text{Total waiting time}}{\text{Actual production output}}$$

The due-date of each part family was described in Chapter 5. The due-date of a part family was determined by the arrival time and part's processing time. Part family 6 had the largest allowance (= due-date - arrival time) value due to its longest processing time. Part family 4 had the smallest allowance due to its shortest processing time.

As previously described, the arrival time of each of thirty-five parts was assumed to be zero when the simulation started. However, a processed part was assigned a specific arrival time when the part returned to its original storage area as a raw material. Average production lateness per part was determined by the total production lateness divided by the actual production output under a decision rule set.

Table 7-12 presents both the total production lateness and the average production lateness per part. The lateness values are the real time values regenerated from the model time using the time scaling factor for a decision rule set. Each decision rule set is assigned a relative rank in each category. Every decision rule set showed a negative production lateness (earliness). This means that the FMS model processed and released parts before due-dates with the failures and idle times of major components no matter which decision rule set was used.

8. Relative rank of all decision rule sets

In the previous sections, a decision rule set was assigned a relative rank for each performance criterion. The relative rank can

Table 7-12. Production lateness and its rank

| Set | Decision rule set | Total production lateness (hrs.:rank) | Average production lateness (hrs.:rank) |
|---|---|---|---|
| 1 | RANDOM/RANDOM | - 687.5324:10 | - 1.0449:10 |
| 2 | RANDOM/FMFS | - 520.0507:14 | - 0.7940:14 |
| 3 | RANDOM/NINQ | - 848.7736:7 | - 1.2744:7 |
| 4 | RANDOM/WINQ | - 902.5636:6 | - 1.3273:6 |
| 5 | FSFS/RANDOM | - 716.8891:9 | - 1.0652:9 |
| 6 | FSFS/FMFS | - 960.1203:3 | - 1.4309:2 |
| 7 | FSFS/NINQ | - 982.4617:2 | - 1.4197:3 |
| 8 | FSFS/WINQ | - 921.3955:4 | - 1.3610:5 |
| 9 | SPT/RANDOM | - 471.0215:17 | - 0.7041:18 |
| 10 | SPT/FMFS | - 541.3993:11 | - 0.8649:11 |
| 11 | SPT/NINQ | - 165.7094:25 | - 0.2242:25 |
| 12 | SPT/WINQ | - 532.1745:13 | - 0.7280:16 |
| 13 | DDATE/RANDOM | - 397.7716:20 | - 0.5990:20 |
| 14 | DDATE/FMFS | - 512.1764:16 | - 0.7892:15 |
| 15 | DDATE/NINQ | - 31.8666:28 | - 0.0444:28 |
| 16 | DDATE/WINQ | - 72.9090:26 | - 0.1051:26 |
| 17 | SLACK/RANDOM | - 177.0825:24 | - 0.2728:24 |
| 18 | SLACK/FMFS | - 539.9585:12 | - 0.8228:13 |
| 19 | SLACK/NINQ | - 197.9445:23 | - 0.2856:23 |
| 20 | SLACK/WINQ | - 39.0357:27 | - 0.0588:27 |
| 21 | S/PT/RANDOM | - 425.6491:19 | - 0.6579:19 |
| 22 | S/PT/FMFS | - 467.2121:18 | - 0.7277:17 |
| 23 | S/PT/NINQ | - 299.0134:22 | - 0.4470:22 |
| 24 | S/PT/WINQ | - 388.4706:21 | - 0.5781:21 |
| 25 | VALUE/RANDOM | - 800.9347:8 | - 1.2574:8 |
| 26 | VALUE/FMFS | - 512.9028:15 | - 0.8246:12 |
| 27 | VALUE/NINQ | - 918.0388:5 | - 1.3702:4 |
| 28 | VALUE/WINQ | -1025.0576:1 | - 1.5461:1 |

$$\text{Average production lateness} = \frac{\text{Total production lateness}}{\text{Actual production ouput}}$$

be summarized for all decision rule sets. Table 7-13 presents a summary of the ranks under the performance criteria . According to Table 7-13, the NINQ and WINQ rules dominated other decision rules for machine center selection. Also, rules such as FSFS, SPT, DDATE-SLACK and VALUE dominated other decision rules for part selection.

## C. Analysis Procedure

### 1. Overview

In each of six performance criteria, the best performers can be selected. The best decision rule set can be indicated by the correlation coefficient between performance criteria, fetch rate and processing rate for a part family.

The performance of each decision rule set was dependent upon both the failures and idle times. The effects of the failures and idle times are described in this section. Finally, the time point at which the FMS model stabilized under a decision rule set is also presented.

### 2. Correlation between performance criteria

A correlation analysis (32) has been adopted in this research to analyze the performance criteria values obtained for twenty-eight decision rule sets. For any two criteria values among six performance criteria values, the sample correlation coefficient, r, can be determined by the following equation:

Table 7-13. Relative ranks of all decision rule sets

| Set | Decision rule set | A | B | C | D | E | F | G | H | I | J | K | L | M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Performance criteria | | | | | | | | | | | | |
| 1 | RANDOM/RANDOM | 9 | 28 | 28 | 19 | 15 | 9 | 18 | 19 | 28 | 20 | 20 | 10 | 10 |
| 2 | RANDOM/FMFS | 11 | 23 | 26 | 20 | 20 | 27 | 21 | 7 | 10 | 26 | 24 | 14 | 14 |
| 3 | RANDOM/NINQ | 1 | 26 | 27 | 16 | 16 | 4 | 13 | 16 | 24 | 9 | 9 | 7 | 7 |
| 4 | RANDOM/WINQ | 4 | 18 | 11 | 8 | 14 | 15 | 9 | 23 | 11 | 10 | 10 | 6 | 6 |
| 5 | FSFS/RANDOM | 10 | 19 | 20 | 10 | 10 | 5 | 10 | 27 | 22 | 19 | 19 | 9 | 9 |
| 6 | FSFS/FMFS | 2 | 22 | 23 | 12 | 9 | 6 | 11 | 5 | 4 | 27 | 26 | 3 | 2 |
| 7 | FSFS/NINQ | 3 | 21 | 14 | 7 | 7 | 12 | 6 | 14 | 27 | 16 | 13 | 2 | 3 |
| 8 | FSFS/WINQ | 7 | 13 | 9 | 9 | 13 | 3 | 8 | 25 | 21 | 14 | 11 | 4 | 5 |
| 9 | SPT/RANDOM | 12 | 20 | 12 | 14 | 24 | 22 | 14 | 8 | 6 | 17 | 17 | 17 | 18 |
| 10 | SPT/FMFS | 15 | 3 | 21 | 27 | 28 | 7 | 27 | 20 | 26 | 23 | 27 | 11 | 11 |
| 11 | SPT/NINQ | 23 | 27 | 8 | 1 | 4 | 2 | 2 | 22 | 6 | 5 | 4 | 25 | 25 |
| 12 | SPT/WINQ | 28 | 24 | 2 | 2 | 2 | 1 | 1 | 3 | 8 | 3 | 3 | 13 | 16 |
| 13 | DDATE/RANDOM | 16 | 16 | 18 | 17 | 22 | 20 | 17 | 26 | 23 | 15 | 16 | 20 | 20 |
| 14 | DDATE/FMFS | 14 | 8 | 19 | 22 | 17 | 24 | 24 | 17 | 17 | 24 | 22 | 16 | 15 |
| 15 | DDATE/NINQ | 24 | 25 | 12 | 3 | 3 | 16 | 3 | 2 | 19 | 2 | 2 | 28 | 28 |
| 16 | DDATE/WINQ | 25 | 14 | 6 | 5 | 5 | 11 | 5 | 4 | 16 | 4 | 5 | 26 | 26 |
| 17 | SLACK/RANDOM | 26 | 1 | 3 | 22 | 23 | 21 | 23 | 28 | 1 | 11 | 14 | 24 | 24 |
| 18 | SLACK/FMFS | 13 | 7 | 5 | 20 | 25 | 19 | 20 | 12 | 12 | 21 | 21 | 12 | 13 |
| 19 | SLACK/NINQ | 22 | 15 | 6 | 6 | 6 | 23 | 7 | 21 | 20 | 7 | 7 | 23 | 23 |
| 20 | SLACK/WINQ | 27 | 11 | 10 | 4 | 1 | 14 | 4 | 1 | 2 | 1 | 1 | 27 | 27 |
| 21 | S/PT/RANDOM | 19 | 9 | 15 | 24 | 27 | 8 | 22 | 24 | 15 | 18 | 18 | 19 | 19 |
| 22 | S/PT/FMFS | 21 | 4 | 22 | 25 | 12 | 13 | 25 | 11 | 9 | 25 | 25 | 18 | 17 |
| 23 | S/PT/NINQ | 17 | 17 | 17 | 14 | 19 | 28 | 16 | 18 | 25 | 6 | 6 | 22 | 22 |
| 24 | S/PT/WINQ | 20 | 6 | 1 | 11 | 18 | 17 | 12 | 6 | 13 | 8 | 8 | 21 | 21 |
| 25 | VALUE/RANDOM | 8 | 10 | 24 | 26 | 21 | 10 | 26 | 10 | 14 | 22 | 23 | 8 | 8 |
| 26 | VALUE/FMFS | 18 | 5 | 25 | 28 | 25 | 18 | 28 | 9 | 18 | 28 | 28 | 15 | 12 |
| 27 | VALUE/NINQ | 5 | 12 | 16 | 13 | 8 | 26 | 15 | 15 | 3 | 13 | 12 | 5 | 4 |
| 28 | VALUE/WINQ | 6 | 2 | 4 | 18 | 11 | 25 | 19 | 13 | 5 | 12 | 15 | 1 | 1 |

A = Actual system effectivity
B = Total traveling time     C = Average traveling time per part
D = Actual production output     E = Achievement rate
F = Total throughput time     F = Average throughput time per part
H = Work remaining measure for work-in-process inventory
I = Imminent operation work content for work-in-process inventory
J = Total waiting time     K = Average waiting time per part
L = Total production lateness
M = Average production lateness per part

$$r = \frac{n \cdot \sum_{i=1}^{n} x(i) \cdot y(i) - (\sum_{i=1}^{n} x(i))(\sum_{i=1}^{n} y(i))}{\sqrt{n \cdot \sum_{i=1}^{n} x(i)^2 - (\sum_{i=1}^{n} x(i))^2}\sqrt{n \cdot \sum_{i=1}^{n} y(i)^2 - (\sum_{i=1}^{n} y(i))^2}} \quad (7\text{-}1)$$

where:

r = the sample correlation coefficient ($-1 <= r <= 1$);
n = the sample size (= 28);
x(i) = one of two performance criteria values for decision rule set i;

y(i) = the other performance criterion value for decision rule set i.

The r value measures the strength of the linear relationship between X and Y. If the r has a negative value, the relationship between two performance criteria is inverse. Conversely, the relationship between two performance criteria is direct when the r has a positive value.

Equation 7-1 was applied to the performance criteria. The r values obtained are presented in Table 7-14. Table 7-14 shows that the absolute values of five correlation coefficients among thirty-four coefficients are greater than 0.8. They are the coefficients for the following relationships:

- A direct relationship between the total number of fetches and the actual production output (r= 0.9409);
- A direct relationship between the actual system effectivity and the effectivity for the machine center cell (r= 0.9606);
- An inverse relationship between the actual system effectivity and the average production lateness/part (r= -0.9086);
- An inverse relationship between the actual production output and the average throughput time/part (r= -0.9306);

Table 7-14. Correlation cofficient between performance criteria

| | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| A | — | .1485 | -.3372 | .3784 | .5075 | .2162 | .5016 | -.9086 |
| B | — | — | -.4603 | .4330 | .2121 | .4308 | .5580 | -.3182 |
| C | — | — | — | -.9306 | -.4813 | -.1217 | -.8306 | .3406 |
| D | — | — | — | — | .4966 | .1419 | .7422 | -.2533 |
| E | — | — | — | — | — | .2810 | .5144 | -.4538 |
| F | — | — | — | — | — | — | .0878 | -.1166 |
| G | — | — | — | — | — | — | — | -.5473 |

A = actual system effectivity
B = average traveling time per part
C = actual production output
D = average throughput time per part
E = work-in-process inventory (the work remaining)
F = work-in-process inventory (the imminent operation work content)
G = work-in-process inventory (average waiting time per part)
H = average production lateness

In addition, the following relationships were investigated to analyze the performance of a decision rule set:

simulation run time vs. total number of fetches : r = 0.4522

simulation run time vs. actual production output : r = 0.4642

total number of fetches vs. actual production output: r = 0.9409

actual system effectivity vs. effectivity for the AS/RS cart: r = 0.0851

actual system effectivity vs. effectivity for the machine center cell : r = 0.9606

actual system effectivity vs. effectivity for the turning cell : r = 0.0817

- An inverse relationship between the actual production output and the average waiting time/part (r= -0.8306).

No significant relationships were obtained for other performance criteria. For example, the average travelling time/part is relatively independent of the work remaining as a work-in-process inventory criterion (r= 0.2121).

The following results can be concluded from Table 7-14:

- The actual system effectivity of the model was strongly dependent on the machine center's effectivity;
- If a decision rule set fetched more parts during the simulation than other decision rule sets, the model manufactured more parts under the rule set;
- If a decision rule set had higher actual system effectivity than other decision rule sets, the rule set generated smaller average production lateness per part;
- If the model manufactured more parts under a decision rule set, the average throughput time per part was smaller under the rule set;
- If the model manufactured more parts under a decision rule set, the average waiting time per part on the machine center cell was smaller than other decision rule sets;
- The actual production output was the manufacturing capacity of the model in a fixed simulation run time. The actual production output was not affected by the specific simulation run time which was determined by a time scaling factor for a decision rule set.

3. Fetch rate for a storage area

Every decision rule set had a specific fetch rate for each of eight storage areas. As described previously, storage area 8 was the most distant storage area. Storage area 1 was the nearest storage area to the AS/RS cart's starting position. However, storage area 8 was independent of a part selection rule. A semifinished part stored on storage area 8 was retrieved with the highest priority. Therefore, storage area 7 was the most distant storage area for which a part selection rule was applied.

If a decision rule set selected storage area 1 frequently to fetch a part, the rule set would be expected to generate a small traveling time, small throughput time and low effectivity of the AS/RS cart. In contrast, if a decision rule set selected storage area 7 frequently, the rule set would be expected to generate a large traveling time, large throughput time and high effectivity of the AS/RS cart.

The fetch rate for each storage area was computed and presented in Table 7-4a. The fetch rate was determined by total number fetches for a storage area divided by the total number of fetches for parts. Table 7-15 presents the fetch rate for each storage area and a relative rank under every decision rule set. The FSFS rule as a part selection rule was expected to have the highest number of fetches for storage area 1. However, the SPT rule had the highest number of fetches for this storage area. This means that the fetch rate for each storage area was heavily dependent upon what types of parts were stored on each storage area in every fetch. Under a decision rule set, each of eight storage areas had a new part order in every fetch.

The initial part allocation was illustrated in both Chapter 3 and Chapter 6. According to the part allocation, storage areas 2 and 3 did not contain part family 4 with the shortest processing time while storage areas 4 and 5 did not contain part family 6 with the longest processing time at the beginning of the simulation. Recall

Table 7-15. Fetch rate and rank for a storage area

| Set | Decision rule set | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | RANDOM/RANDOM | .1064 | .1012 | .0938 | .1117 | .1085 | .1075 | .0980 | .2729 |
| | | 16 | 16 | 17 | 20 | 15 | 1 | 9 | 8 |
| 2 | RANDOM/FMFS | .1051 | .1019 | .1072 | .1019 | .1040 | .1019 | .1072 | .2707 |
| | | 17 | 15 | 8 | 28 | 18 | 4 | 2 | 11 |
| 3 | RANDOM/NINQ | .0954 | .1101 | .0933 | .1038 | .1006 | .1038 | .1237 | .2694 |
| | | 23 | 8 | 18 | 27 | 23 | 3 | 1 | 13 |
| 4 | RANDOM/WINQ | .1104 | .1073 | .1032 | .1104 | .1001 | .1042 | .0991 | .2652 |
| | | 12 | 10 | 13 | 23 | 24 | 2 | 8 | 15 |
| 5 | FSFS/RANDOM | .1351 | .1393 | .1236 | .1277 | .1099 | .0597 | .0429 | .2618 |
| | | 8 | 5 | 4 | 14 | 14 | 21 | 22 | 18 |
| 6 | FSFS/FMFS | .1189 | .1053 | .1063 | .1105 | .1116 | .1000 | .0863 | .2611 |
| | | 9 | 13 | 9 | 22 | 10 | 6 | 15 | 20 |
| 7 | FSFS/NINQ | .1667 | .1543 | .1317 | .1337 | .0638 | .0535 | .0412 | .2551 |
| | | 4 | 1 | 3 | 12 | 28 | 24 | 23 | 24 |
| 8 | FSFS/WINQ | .1680 | .1504 | .1214 | .1266 | .1027 | .0425 | .0239 | .2645 |
| | | 3 | 2 | 5 | 15 | 21 | 26 | 26 | 16 |
| 9 | SPT/RANDOM | .1504 | .1143 | .0865 | .1493 | .1370 | .0556 | .0278 | .2791 |
| | | 6 | 7 | 21 | 9 | 8 | 23 | 25 | 3 |
| 10 | SPT/FMFS | .1160 | .1039 | .1050 | .1160 | .1039 | .0996 | .0744 | .2812 |
| | | 10 | 14 | 12 | 18 | 20 | 7 | 20 | 1 |
| 11 | SPT/NINQ | .2127 | .0480 | .0275 | .2363 | .1902 | .0294 | .0098 | .2461 |
| | | 2 | 27 | 28 | 2 | 2 | 27 | 28 | 28 |
| 12 | SPT/WINQ | .2189 | .0428 | .0398 | .2438 | .1930 | .0129 | .0010 | .2478 |
| | | 1 | 28 | 27 | 1 | 1 | 28 | 27 | 27 |
| 13 | DDATE/RANDOM | .0877 | .0825 | .0835 | .1555 | .1441 | .0825 | .0908 | .2735 |
| | | 26 | 22 | 22 | 7 | 7 | 16 | 12 | 7 |
| 14 | DDATE/FMFS | .1097 | .0989 | .1022 | .1204 | .1043 | .0946 | .1032 | .2667 |
| | | 13 | 17 | 14 | 17 | 19 | 10 | 5 | 14 |
| 15 | DDATE/NINQ | .0799 | .0718 | .0718 | .2063 | .1759 | .0607 | .0779 | .2558 |
| | | 28 | 26 | 24 | 3 | 3 | 20 | 18 | 23 |
| 16 | DDATE/WINQ | .0948 | .0742 | .0691 | .1876 | .1670 | .0670 | .0814 | .2588 |
| | | 24 | 24 | 26 | 6 | 5 | 18 | 17 | 21 |
| 17 | SLACK/RANDOM | .0959 | .0810 | .0885 | .1503 | .1343 | .0874 | .0885 | .2740 |
| | | 22 | 23 | 20 | 8 | 9 | 15 | 14 | 6 |
| 18 | SLACK/FMFS | .1041 | .1073 | .1073 | .1115 | .1073 | .0915 | .0925 | .2787 |
| | | 20 | 10 | 7 | 21 | 16 | 12 | 11 | 4 |
| 19 | SLACK/NINQ | .0896 | .0855 | .0742 | .1895 | .1586 | .0742 | .0752 | .2533 |
| | | 25 | 21 | 23 | 5 | 6 | 17 | 19 | 25 |
| 20 | SLACK/WINQ | .0808 | .0735 | .0714 | .2025 | .1742 | .0640 | .0829 | .2508 |
| | | 27 | 25 | 25 | 4 | 4 | 19 | 16 | 26 |

Table 7-15. (continued)

| Set | Decision rule set | Fetch rate and rank for storage area 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| 21 | S/PT/RANDOM | .1095 | .0946 | .0914 | .1158 | .1116 | .0914 | .1052 | .2806 |
| | | 14 | 20 | 19 | 19 | 10 | 13 | 4 | 2 |
| 22 | S/PT/FMFS | .1028 | .1061 | .1061 | .1083 | .1105 | .1007 | .1018 | .2637 |
| | | 21 | 12 | 10 | 24 | 13 | 5 | 7 | 17 |
| 23 | S/PT/NINQ | .1042 | .0958 | .0969 | .1292 | .1115 | .0979 | .0938 | .2708 |
| | | 19 | 19 | 15 | 13 | 12 | 9 | 10 | 10 |
| 24 | S/PT/WINQ | .1048 | 0.985 | .0944 | .1245 | .1068 | .0985 | .1027 | .2697 |
| | | 18 | 18 | 16 | 16 | 17 | 8 | 6 | 12 |
| 25 | VALUE/RANDOM | .1133 | .1187 | .1122 | .1046 | .0980 | .0904 | .0904 | .2723 |
| | | 11 | 6 | 6 | 25 | 25 | 14 | 13 | 9 |
| 26 | VALUE/FMFS | .1074 | .1074 | .1052 | .1030 | .1019 | .0930 | .1063 | .2757 |
| | | 15 | 9 | 11 | 26 | 22 | 11 | 3 | 5 |
| 27 | VALUE/NINQ | .1435 | .1498 | .1477 | .1350 | .0643 | .0559 | .0454 | .2584 |
| | | 7 | 3 | 1 | 11 | 27 | 22 | 21 | 22 |
| 28 | VALUE/WINQ | .1552 | .1424 | .1382 | .1456 | .0659 | .0531 | .0383 | .2614 |
| | | 5 | 4 | 2 | 10 | 26 | 25 | 24 | 19 |

that every processed part returned to its original storage area. Therefore, storage areas 2 and 3 were not replenished with part family 4. Storage areas 4 and 5 were not replenished with part family 6 during the simulation. This means that the SPT, DDATE, SLACK and S/PT rules had low fetch rates for storage areas 2 and 3 because these rules gave high priority to parts with short processing times. In contrast, the rules RANDOM, FSFS and VALUE had low fetch rates for storage areas 4 and 5 because these rules gave high priority to parts with long processing times.

4. Part family fetch rate

The part family fetch rate is an important factor in analyzing the performance of each decision rule set. The fetch rate is total number of parts fetched from a storage area divided by the total number of fetches for parts under a decision rule set.

If a decision rule set frequently fetched a part family with the longest processing time (part family 6), the rule set would have high actual system effectvity, low production output, high total throughput time, high work-in-process inventory and low total production lateness. From Chapter 5, part family 6 had both the longest processing time and the longest due-date. Part family 4 had both the shortest processing time and the shortsst due-date. If a decision rule set fetched part family 4 frequently, the decision rule set would have low actual s ystem effectivity, high production outptut, low total throughput time, high production output, low work-in-process inventory and high total production lateness.

When a decision rule set selected parts with the short processing time from the AS/RS cell, the following situations would be expected in the model:

- Large arrival rate to the seven storage areas. That is, the machine center cell would process parts with the short processing time quicker than parts with the long processing times. Then, each of seven storage area would be filled with raw materials more quickly. This means that each storage area would have various parts to be selected by a part selection rule;
- Small effect of failures on the machine center cell. A machine center could finish its short process before a long failure time would occur in the machine center.

Part fetches were affected by both the failures of major system components and the maximum queue length in each workcenter's waiting line.

If either a major system component failed or a workcenter was full with the maximum queue length, the performance criteria were affected as follows:

- The actual system effectivity was low;
- The traveling time of parts was large;
- The total manufacturing throughput time was large;
- The actual production output was low;
- The work-in-process inventory was high;
- The total production lateness was high.

Table 7-16 presents total number of fetches for each of seven part families. Table 7-17a shows the part fetch rate and its relative rank for a part family. Table 7-17b presents both the fetch rate for parts to be routed to the machine center cell and the fetch rate for parts to be routed to the turning cell. The first operation of part families 1, 3 and 5 was processed by the turning cell. The rest of the part families and second operation of part families 1, 3 and 5 were processed by the machine center cell.

From Table 7-17a, the SPT/NINQ rule set has the largest fetch rate for part family 4. The VALUE/WINQ rule set has the smallest fetch rate. For part family 6, the FSFS/FMFS rule set has the largest rate and the SPT/WINQ rule set has the smallest rate.

From Table 7-17b, the SPT/NINQ rule set has the largest fetch rate for the machine center cell while the SLACK/FMFS rule set has the smallest fetch rate. The SLACK/FMFS rule set has the largest fetch rate for the turning cell while the the SPT/NINQ rule set has the smallest fetch rate.

5. Processing rates and completion rates for part families

Six machine centers processed parts fetched from the AS/RS cell. Parts 1, 3 and 5 were routed to a machine center to complete their processes after the turning cell operation. The rest of the parts were directly routed to a machine center.

Table 7-16. Total number of fetches for part families

| Set | Decision rule set | Part family 1 | 2 | 3 | 4 | 5 | 6 | 7 | SF | A | B |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | RANDOM/RANDOM | 85 | 102 | 85 | 128 | 95 | 82 | 113 | 259 | 684 | 265 |
| 2 | RANDOM/FMFS | 86 | 97 | 87 | 126 | 89 | 80 | 122 | 255 | 680 | 262 |
| 3 | RANDOM/NINQ | 84 | 105 | 82 | 124 | 93 | 88 | 121 | 257 | 695 | 259 |
| 4 | RANDOM/WINQ | 85 | 107 | 86 | 126 | 92 | 88 | 128 | 257 | 706 | 263 |
| 5 | FSFS/RANDOM | 89 | 106 | 79 | 116 | 88 | 79 | 148 | 250 | 699 | 256 |
| 6 | FSFS/FMFS | 84 | 107 | 81 | 126 | 85 | 93 | 126 | 248 | 700 | 250 |
| 7 | FSFS/NINQ | 102 | 108 | 70 | 117 | 80 | 87 | 160 | 248 | 720 | 252 |
| 8 | FSFS/WINQ | 106 | 104 | 73 | 118 | 78 | 85 | 145 | 255 | 707 | 257 |
| 9 | SPT/RANDOM | 100 | 99 | 83 | 131 | 91 | 69 | 127 | 271 | 697 | 274 |
| 10 | SPT/FMFS | 89 | 98 | 82 | 116 | 87 | 81 | 104 | 257 | 656 | 258 |
| 11 | SPT/NINQ | 104 | 99 | 71 | 223 | 80 | 46 | 146 | 251 | 765 | 255 |
| 12 | SPT/WINQ | 102 | 97 | 70 | 219 | 80 | 37 | 151 | 249 | 753 | 252 |
| 13 | DDATE/RANDOM | 87 | 110 | 91 | 138 | 88 | 65 | 117 | 262 | 692 | 266 |
| 14 | DDATE/FMFS | 81 | 100 | 90 | 124 | 84 | 79 | 124 | 248 | 675 | 255 |
| 15 | DDATE/NINQ | 86 | 105 | 91 | 184 | 80 | 42 | 148 | 253 | 732 | 257 |
| 16 | DDATE/WINQ | 86 | 104 | 93 | 172 | 76 | 48 | 140 | 251 | 715 | 255 |
| 17 | SLACK/RANDOM | 80 | 101 | 93 | 145 | 90 | 63 | 109 | 257 | 675 | 263 |
| 18 | SLACK/FMFS | 86 | 107 | 89 | 117 | 95 | 73 | 119 | 265 | 681 | 270 |
| 19 | SLACK/NINQ | 80 | 109 | 89 | 167 | 82 | 57 | 141 | 246 | 720 | 251 |
| 20 | SLACK/WINQ | 81 | 109 | 91 | 168 | 73 | 43 | 149 | 239 | 708 | 245 |
| 21 | S/PT/RANDOM | 84 | 96 | 94 | 117 | 88 | 73 | 125 | 264 | 675 | 266 |
| 22 | S/PT/FMFS | 78 | 106 | 82 | 130 | 88 | 77 | 112 | 241 | 666 | 248 |
| 23 | S/PT/NINQ | 83 | 98 | 89 | 138 | 95 | 67 | 130 | 260 | 693 | 267 |
| 24 | S/PT/WINQ | 77 | 95 | 94 | 143 | 94 | 72 | 129 | 260 | 699 | 265 |
| 25 | VALUE/RANDOM | 91 | 109 | 70 | 106 | 93 | 87 | 112 | 250 | 664 | 254 |
| 26 | VALUE/FMFS | 84 | 94 | 80 | 106 | 91 | 84 | 115 | 249 | 648 | 255 |
| 27 | VALUE/NINQ | 99 | 105 | 76 | 105 | 77 | 89 | 152 | 245 | 696 | 252 |
| 28 | VALUE/WINQ | 104 | 113 | 76 | 99 | 72 | 90 | 141 | 246 | 689 | 252 |

Part family 4 had the shortest processing time.
Part family 6 had the longest processing time.
SF = Semifinished parts
A = Total number of parts routed to the machine center cell
B = Total number of parts routed to the turning cell

Table 7-17a. Fetch rate and its rank for a part family

| Set | Decision rule set | Part family 1 | 2 | 3 | 4 | 5 | 6 | 7 | SF |
|---|---|---|---|---|---|---|---|---|---|
| 1 | RANDOM/RANDOM | .0896 | .1075 | .0896 | .1349 | .1001 | .0864 | .1191 | .2729 |
| | | 15 | 16 | 15 | 12 | 2 | 11 | 26 | 8 |
| 2 | RANDOM/FMFS | .0913 | .1030 | .0924 | .1338 | .0944 | .0848 | .1294 | .2707 |
| | | 12 | 22 | 10 | 14 | 12 | 13 | 19 | 11 |
| 3 | RANDOM/NINQ | .0881 | .1101 | .0860 | .1300 | .0975 | .0922 | .1268 | .2694 |
| | | 19 | 13 | 18 | 17 | 6 | 6 | 21 | 13 |
| 4 | RANDOM/WINQ | .0877 | .1104 | .0888 | .1300 | .0949 | .0908 | .1321 | .2652 |
| | | 20 | 12 | 16 | 17 | 11 | 7 | 17 | 15 |
| 5 | FSFS/RANDOM | .0932 | .1110 | .0827 | .1215 | .0921 | .0827 | .1550 | .2618 |
| | | 10 | 10 | 21 | 23 | 15 | 15 | 4 | 18 |
| 6 | FSFS/FMFS | .0884 | .1126 | .0853 | .1316 | .0895 | .0979 | .1326 | .2611 |
| | | 18 | 6 | 20 | 16 | 18 | 1 | 16 | 20 |
| 7 | FSFS/NINQ | .1049 | .1111 | .0720 | .1204 | .0823 | .0895 | .1646 | .2551 |
| | | 3 | 9 | 26 | 24 | 20 | 8 | 1 | 24 |
| 8 | FSFS/WINQ | .1100 | .1079 | .0757 | .1224 | .0809 | .0882 | .1504 | .2645 |
| | | 2 | 14 | 25 | 22 | 22 | 10 | 5 | 16 |
| 9 | SPT/RANDOM | .1030 | .1020 | .0855 | .1349 | .0937 | .0711 | .1308 | .2791 |
| | | 5 | 24 | 19 | 12 | 13 | 19 | 18 | 3 |
| 10 | SPT/FMFS | .0974 | .1072 | .0897 | .1269 | .0952 | .0886 | .1138 | .2812 |
| | | 9 | 18 | 13 | 19 | 10 | 9 | 28 | 1 |
| 11 | SPT/NINQ | .1020 | .0971 | .0696 | .2186 | .0784 | .0451 | .1431 | .2461 |
| | | 6 | 27 | 28 | 1 | 25 | 25 | 11 | 28 |
| 12 | SPT/WINQ | .1015 | .0965 | .0697 | .2179 | .0796 | .0368 | .1502 | .2478 |
| | | 7 | 28 | 27 | 2 | 24 | 28 | 6 | 27 |
| 13 | DDATE/RANDOM | .0908 | .1480 | .0950 | .1441 | .0919 | .0678 | .1221 | .2735 |
| | | 13 | 4 | 7 | 9 | 16 | 21 | 24 | 7 |
| 14 | DDATE/FMFS | .0871 | .1075 | .0968 | .1333 | .0903 | .0849 | .1333 | .2677 |
| | | 21 | 16 | 4 | 15 | 17 | 12 | 14 | 14 |
| 15 | DDATE/NINQ | .0870 | .1062 | .0920 | .1860 | .0809 | .0425 | .1496 | .2558 |
| | | 22 | 20 | 11 | 3 | 22 | 27 | 8 | 23 |
| 16 | DDATE/WINQ | .0887 | .1072 | .0959 | .1773 | .0784 | .0495 | .1443 | .2588 |
| | | 17 | 18 | 5 | 4 | 25 | 24 | 10 | 21 |
| 17 | SLACK/RANDOM | .0853 | .1077 | .0991 | .1546 | .0959 | .0672 | .1162 | .2740 |
| | | 24 | 15 | 2 | 7 | 9 | 22 | 27 | 6 |
| 18 | SLACK/FMFS | .0904 | .1125 | .0936 | .1230 | .0999 | .0768 | .1251 | .2787 |
| | | 14 | 7 | 8 | 21 | 4 | 17 | 22 | 4 |
| 19 | SLACK/NINQ | .0824 | .1123 | .0917 | .1720 | .0844 | .0587 | .1452 | .2533 |
| | | 27 | 8 | 12 | 6 | 19 | 23 | 9 | 25 |
| 20 | SLACK/WINQ | .0850 | .1144 | .0955 | .1763 | .0766 | .0451 | .1563 | .2508 |
| | | 26 | 5 | 6 | 5 | 27 | 25 | 3 | 26 |

Table 7-17a. (continued)

| Set | Decision rule set | Part family 1 | 2 | 3 | 4 | 5 | 6 | 7 | SF |
|---|---|---|---|---|---|---|---|---|---|
| 21 | S/PT/RANDOM | .0893 | .1020 | .0999 | .1243 | .0935 | .0776 | .1328 | .2806 |
| | | 16 | 24 | 1 | 20 | 14 | 16 | 15 | 2 |
| 22 | S/PT/FMFS | .0853 | .1160 | .0897 | .1422 | .0963 | .0842 | .1225 | .2637 |
| | | 24 | 3 | 13 | 11 | 8 | 14 | 23 | 17 |
| 23 | S/PT/NINQ | .0865 | .1021 | .0927 | .1438 | .0990 | .0698 | .1354 | .2708 |
| | | 23 | 23 | 9 | 10 | 5 | 20 | 12 | 10 |
| 24 | S/PT/WINQ | .0799 | .0985 | .0975 | .1483 | .0975 | .0747 | .1338 | .2697 |
| | | 28 | 26 | 3 | 8 | 6 | 18 | 13 | 12 |
| 25 | VALUE/RANDOM | .0991 | .1187 | .0763 | .1155 | .1013 | .0940 | .1220 | .2723 |
| | | 8 | 2 | 24 | 26 | 1 | 3 | 25 | 9 |
| 26 | VALUE/FMFS | .0930 | .1041 | .0886 | .1174 | .1008 | .0930 | .1274 | .2757 |
| | | 11 | 21 | 17 | 25 | 3 | 5 | 20 | 5 |
| 27 | VALUE/NINQ | .1044 | .1108 | .0802 | .1108 | .0812 | .0939 | .1603 | .2584 |
| | | 4 | 11 | 23 | 27 | 21 | 4 | 2 | 22 |
| 28 | VALUE/WINQ | .1105 | .1201 | .0808 | .1052 | .0765 | .0956 | .1498 | .2614 |
| | | 1 | 1 | 22 | 28 | 28 | 2 | 7 | 19 |

SF = Semifinished parts

Table 7-17b. Fetch rate and rank for the workcenter cell

| Set | Decision rule set | Fetch rate for machine centers | Fetch rate for the turning cell |
|---|---|---|---|
| 1 | RANDOM/RANDOM | 0.7208:22 | 0.2792:7 |
| 2 | RANDOM/FMFS | 0.7211:20 | 0.2778:9 |
| 3 | RANDOM/NINQ | 0.7285:15 | 0.2715:14 |
| 4 | RANDOM/WINQ | 0.7286:14 | 0.2714:15 |
| 5 | FSFS/RANDOM | 0.7319:12 | 0.2681:17 |
| 6 | FSFS/FMFS | 0.7368:8 | 0.2632:21 |
| 7 | FSFS/NINQ | 0.7407:5 | 0.2593:24 |
| 8 | FSFS/WINQ | 0.7334:10 | 0.2666:19 |
| 9 | SPT/RANDOM | 0.7178:24 | 0.2822:5 |
| 10 | SPT/FMFS | 0.7177:25 | 0.2823:4 |
| 11 | SPT/NINQ | 0.7500:1 | 0.2500:28 |
| 12 | SPT/WINQ | 0.7493:2 | 0.2507:27 |
| 13 | DDATE/RANDOM | 0.7223:19 | 0.2777:10 |
| 14 | DDATE/FMFS | 0.7258:16 | 0.2742:13 |

Table 7-17b. (continued)

| Set | Decision rule set | Fetch rate for machine centers | Fetch rate for the turning cell |
|---|---|---|---|
| 15 | DDATE/NINQ | 0.7401:6 | 0.2599:23 |
| 16 | DDATE/WINQ | 0.7371:7 | 0.2629:22 |
| 17 | SLACK/RANDOM | 0.7196:23 | 0.2804:6 |
| 18 | SLACK/FMFS | 0.7161:28 | 0.2889:1 |
| 19 | SLACK/NINQ | 0.7415:4 | 0.2585:25 |
| 20 | SLACK/WINQ | 0.7429:3 | 0.2571:26 |
| 21 | S/PT/RANDOM | 0.7173:27 | 0.2827:2 |
| 22 | S/PT/FMFS | 0.7287:13 | 0.2713:16 |
| 23 | S/PT/NINQ | 0.7219:21 | 0.2781:8 |
| 24 | S/PT/WINQ | 0.7251:17 | 0.2749:12 |
| 25 | VALUE/RANDOM | 0.7233:18 | 0.2767:11 |
| 26 | VALUE/FMFS | 0.7176:26 | 0.2824:3 |
| 27 | VALUE/NINQ | 0.7342:9 | 0.2658:20 |
| 28 | VALUE/WINQ | 0.7322:11 | 0.2678:18 |

The processing rate for each part family is defined as the total number of processed parts of a family divided by the actual production output under a decision rule set. Table 7-18 presents total number of a processed parts of a family. Table 7-19 presents the processing rate and its relative rank by a part family. From these tables, a decision rule set which had high fetch rate for a part also had a high processing rate.

The completion rate is defined as the total number of processed parts of a family divided by the total number of fetches for that part family under a decision rule set. Table 7-20 presents the completion rate for each part family. The average completion rate is the overall average for all completion rates of the seven part families. Every decision rule set has an average completion rate which is more than 95%. This means that every part fetched from a

Table 7-18. Total number of processed parts by family

| Set | Decision rule set | Part family 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| 1 | RANDOM/RANDOM | 80 | 98 | 80 | 124 | 91 | 77 | 108 |
| 2 | RANDOM/FMFS | 82 | 92 | 82 | 122 | 84 | 76 | 117 |
| 3 | RANDOM/NINQ | 80 | 101 | 78 | 119 | 89 | 83 | 116 |
| 4 | RANDOM/WINQ | 81 | 102 | 81 | 122 | 87 | 83 | 124 |
| 5 | FSFS/RANDOM | 84 | 101 | 75 | 113 | 83 | 74 | 143 |
| 6 | FSFS/FMFS | 80 | 103 | 76 | 121 | 81 | 89 | 121 |
| 7 | FSFS/NINQ | 97 | 104 | 65 | 112 | 76 | 82 | 156 |
| 8 | FSFS/WINQ | 101 | 99 | 68 | 113 | 74 | 80 | 140 |
| 9 | SPT/RANDOM | 96 | 94 | 79 | 126 | 86 | 65 | 123 |
| 10 | SPT/FMFS | 84 | 94 | 78 | 111 | 83 | 76 | 100 |
| 11 | SPT/NINQ | 101 | 94 | 66 | 219 | 76 | 41 | 142 |
| 12 | SPT/WINQ | 97 | 94 | 66 | 215 | 76 | 35 | 148 |
| 13 | DDATE/RANDOM | 83 | 105 | 86 | 134 | 83 | 60 | 113 |
| 14 | DDATE/FMFS | 76 | 96 | 85 | 119 | 79 | 74 | 120 |
| 15 | DDATE/NINQ | 82 | 101 | 87 | 184 | 80 | 40 | 144 |
| 16 | DDATE/WINQ | 82 | 100 | 89 | 168 | 73 | 45 | 137 |
| 17 | SLACK/RANDOM | 75 | 96 | 89 | 141 | 85 | 58 | 105 |
| 18 | SLACK/FMFS | 82 | 103 | 84 | 114 | 90 | 68 | 114 |
| 19 | SLACK/NINQ | 76 | 104 | 84 | 163 | 77 | 52 | 137 |
| 20 | SLACK/WINQ | 80 | 107 | 86 | 166 | 71 | 41 | 148 |
| 21 | S/PT/RANDOM | 79 | 91 | 91 | 113 | 85 | 68 | 120 |
| 22 | S/PT/FMFS | 74 | 101 | 78 | 127 | 83 | 72 | 107 |
| 23 | S/PT/NINQ | 79 | 93 | 84 | 134 | 91 | 62 | 126 |
| 24 | S/PT/WINQ | 72 | 94 | 89 | 138 | 89 | 68 | 125 |
| 25 | VALUE/RANDOM | 87 | 104 | 65 | 102 | 89 | 83 | 107 |
| 26 | VALUE/FMFS | 79 | 89 | 76 | 102 | 86 | 80 | 110 |
| 27 | VALUE/NINQ | 94 | 101 | 71 | 100 | 72 | 84 | 148 |
| 28 | VALUE/WINQ | 99 | 109 | 71 | 94 | 68 | 85 | 137 |

Part family 4 had the shortest processing time.
Part family 6 had the longest processing time.

Table 7-19. Processing rate and rank by part family

| Set | Decision rule set | Part family 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| 1 | RANDOM/RANDOM | .1216 | .1489 | .1216 | .1884 | .1383 | .1170 | .1641 |
| | | 16 | 15 | 13 | 12 | 2 | 11 | 26 |
| 2 | RANDOM/FMFS | .1252 | .1405 | .1252 | .1863 | .1282 | .1160 | .1786 |
| | | 11 | 23 | 9 | 14 | 13 | 12 | 19 |
| 3 | RANDOM/NINQ | .1201 | .1517 | .1171 | .1787 | .1336 | .1246 | .1743 |
| | | 17 | 8 | 19 | 18 | 6 | 6 | 21 |
| 4 | RANDOM/WINQ | .1191 | .1500 | .1191 | .1794 | .1279 | .1221 | .1824 |
| | | 19 | 14 | 17 | 17 | 14 | 7 | 17 |
| 5 | FSFS/RANDOM | .1248 | .1501 | .1114 | .1679 | .1233 | .1100 | .2125 |
| | | 14 | 12 | 21 | 22 | 16 | 15 | 3 |
| 6 | FSFS/FMFS | .1192 | .1535 | .1133 | .1803 | .1207 | .1326 | .1803 |
| | | 18 | 6 | 20 | 16 | 18 | 1 | 18 |
| 7 | FSFS/NINQ | .1402 | .1503 | .0939 | .1618 | .1098 | .1185 | .2254 |
| | | 5 | 10 | 26 | 25 | 21 | 9 | 1 |
| 8 | FSFS/WINQ | .1496 | .1467 | .1007 | .1674 | .1096 | .1185 | .2074 |
| | | 1 | 18 | 25 | 23 | 22 | 9 | 5 |
| 9 | SPT/RANDOM | .1435 | .1405 | .1181 | .1883 | .1286 | .0972 | .1839 |
| | | 3 | 23 | 18 | 13 | 12 | 19 | 16 |
| 10 | SPT/FMFS | .1342 | .1502 | .1246 | .1773 | .1326 | .1214 | .1597 |
| | | 8 | 11 | 10 | 19 | 7 | 8 | 28 |
| 11 | SPT/NINQ | .1367 | .1272 | .0893 | .2963 | .1028 | .0555 | .1922 |
| | | 6 | 28 | 28 | 1 | 26 | 27 | 11 |
| 12 | SPT/WINQ | .1327 | .1286 | .0903 | .2941 | .1040 | .0479 | .2025 |
| | | 9 | 27 | 27 | 2 | 25 | 28 | 7 |
| 13 | DDATE/RANDOM | .1250 | .1581 | .1294 | .2018 | .1250 | .0904 | .1702 |
| | | 13 | 3 | 5 | 9 | 15 | 21 | 23 |
| 14 | DDATE/FMFS | .1171 | .1479 | .1310 | .0834 | .1217 | .1140 | .1849 |
| | | 22 | 16 | 4 | 15 | 17 | 13 | 15 |
| 15 | DDATE/NINQ | .1142 | .1407 | .1212 | .2563 | .1114 | .0557 | .2006 |
| | | 26 | 21 | 15 | 3 | 19 | 26 | 8 |
| 16 | DDATE/WINQ | .1182 | .1441 | .1282 | .2421 | .1052 | .0648 | .1974 |
| | | 20 | 19 | 6 | 4 | 24 | 24 | 10 |
| 17 | SLACK/RANDOM | .1156 | .1479 | .1371 | .2173 | .1310 | .0894 | .1618 |
| | | 23 | 16 | 2 | 7 | 10 | 22 | 27 |
| 18 | SLACK/FMFS | .1252 | .1573 | .1282 | .1740 | .1374 | .1038 | .1740 |
| | | 11 | 4 | 6 | 21 | 4 | 17 | 22 |
| 19 | SLACK/NINQ | .1097 | .1501 | .1212 | .2352 | .1111 | .0750 | .1977 |
| | | 27 | 12 | 15 | 6 | 20 | 23 | 9 |
| 20 | SLACK/WINQ | .1144 | .1531 | .1230 | .2375 | .1016 | .0587 | .2117 |
| | | 25 | 7 | 11 | 5 | 28 | 25 | 4 |

Table 7-19. (continued)

| Set | Decision rule set | Part family 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| 21 | S/PT/RANDOM | .1221 | .1406 | .1406 | .1747 | .1314 | .1051 | .1855 |
| | | 15 | 22 | 1 | 20 | 9 | 16 | 13 |
| 22 | S/PT/FMFS | .1153 | .1573 | .1215 | .1978 | .1293 | .1121 | .1667 |
| | | 24 | 4 | 14 | 11 | 11 | 14 | 25 |
| 23 | S/PT/NINQ | .1181 | .1390 | .1256 | .2003 | .1360 | .0927 | .1883 |
| | | 21 | 26 | 8 | 10 | 5 | 20 | 12 |
| 24 | S/PT/WINQ | .1067 | .1393 | .1319 | .2044 | .1319 | .1007 | .1852 |
| | | 28 | 25 | 3 | 8 | 8 | 18 | 14 |
| 25 | VALUE/RANDOM | .1366 | .1633 | .1020 | .1601 | .1397 | .1303 | .1680 |
| | | 7 | 2 | 24 | 26 | 1 | 2 | 24 |
| 26 | VALUE/FMFS | .1270 | .1431 | .1222 | .1640 | .1383 | .1286 | .1768 |
| | | 10 | 20 | 12 | 24 | 2 | 3 | 20 |
| 27 | VALUE/NINQ | .1403 | .1507 | .1060 | .1492 | .1075 | .1254 | .2209 |
| | | 4 | 9 | 23 | 27 | 23 | 5 | 2 |
| 28 | VALUE/WINQ | .1493 | .1644 | .1071 | .1418 | .1026 | .1282 | .2066 |
| | | 2 | 1 | 21 | 28 | 27 | 4 | 6 |

Table 7-20. Completion rate for a part family

| Set | Decision rule set | Part family 1 | 2 | 3 | 4 | 5 | 6 | 7 | A |
|---|---|---|---|---|---|---|---|---|---|
| 1 | RANDOM/RANDOM | .9412 | .9602 | .9412 | .9688 | .9579 | .9390 | .9558 | .9520 |
| 2 | RANDOM/FMFS | .9535 | .9485 | .9425 | .9683 | .9438 | .9500 | .9590 | .9522 |
| 3 | RANDOM/NINQ | .9524 | .9619 | .9512 | .9597 | .9570 | .9432 | .9587 | .9549 |
| 4 | RANDOM/WINQ | .9529 | .9533 | .9419 | .9683 | .9457 | .9432 | .9688 | .9534 |
| 5 | FSFS/RANDOM | .9438 | .9528 | .9494 | .9741 | .9432 | .9367 | .9662 | .9523 |
| 6 | FSFS/FMFS | .9524 | .9626 | .9383 | .9603 | .9529 | .9570 | .9603 | .9548 |
| 7 | FSFS/NINQ | .9510 | .9630 | .9286 | .9573 | .9500 | .9425 | .9750 | .9525 |
| 8 | FSFS/WINQ | .9528 | .9519 | .9315 | .9576 | .9487 | .9412 | .9655 | .9499 |
| 9 | SPT/RANDOM | .9600 | .9495 | .9518 | .9618 | .9451 | .9420 | .9685 | .9541 |
| 10 | SPT/FMFS | .9438 | .9592 | .9512 | .9569 | .9540 | .9383 | .9615 | .9521 |
| 11 | SPT/NINQ | .9712 | .9495 | .9296 | .9821 | .9500 | .8913 | .9726 | .9495 |
| 12 | SPT/WINQ | .9510 | .9691 | .9429 | .9817 | .9500 | .9459 | .9801 | .9601 |
| 13 | DDATE/RANDOM | .9540 | .9545 | .9451 | .9710 | .9432 | .9231 | .9658 | .9510 |
| 14 | DDATE/FMFS | .9383 | .9600 | .9444 | .9597 | .9405 | .9367 | .9677 | .9496 |
| 15 | DDATE/NINQ | .9535 | .9619 | .9560 | 1.000 | 1.000 | .9524 | .9730 | .9710 |
| 16 | DDATE/WINQ | .9535 | .9615 | .9570 | .9767 | .9605 | .9375 | .9786 | .9608 |

Table 7-20. (continued)

| Set | Decision rule set | Part family 1 | 2 | 3 | 4 | 5 | 6 | 7 | A |
|---|---|---|---|---|---|---|---|---|---|
| 17 | SLACK/RANDOM | .9375 | .9505 | .9570 | .9724 | .9444 | .9206 | .9633 | .9494 |
| 18 | SLACK/FMFS | .9535 | .9626 | .9438 | .9744 | .9474 | .9315 | .9580 | .9530 |
| 19 | SLACK/NINQ | .9500 | .9541 | .9438 | .9760 | .9390 | .9123 | .9716 | .9495 |
| 20 | SLACK/WINQ | .9877 | .9817 | .9451 | .9881 | .9726 | .9535 | .9933 | .9746 |
| 21 | S/PT/RANDOM | .9405 | .9479 | .9681 | .9658 | .9659 | .9315 | .9600 | .9542 |
| 22 | S/PT/FMFS | .9487 | .9528 | .9512 | .9769 | .9432 | .9351 | .9554 | .9519 |
| 23 | S/PT/NINQ | .9518 | .9490 | .9438 | .9710 | .9579 | .9254 | .9652 | .9526 |
| 24 | S/PT/WINQ | .9351 | .9895 | .9468 | .9650 | .9468 | .9444 | .9690 | .9567 |
| 25 | VALUE/RANDOM | .9560 | .9541 | .9286 | .9623 | .9570 | .9540 | .9554 | .9525 |
| 26 | VALUE/FMFS | .9405 | .9468 | .9500 | .9623 | .9451 | .9524 | .9565 | .9505 |
| 27 | VALUE/NINQ | .9495 | .9619 | .9342 | .9524 | .9351 | .9438 | .9737 | .9501 |
| 28 | VALUE/WINQ | .9519 | .9646 | .9342 | .9495 | .9444 | .9444 | 39716 | .9515 |

A = Average completion rate

storage area was processed with 95% probability no matter which decision rule set was applied to the FMS model.

6. Failure effect and idle effect

Every decision rule set evaluated three major system components under a fixed amount of failure times. The total failure time presented in Chapter 5 was 103.052 hours in real time. The total failure time was adjusted by a time scaling factor for each decision rule set. The total amount of idle time of parts until completion of their processes varied with each decision rule set.

The failure effect is defined as an overall rate of failures in the model operation. Idle effect is defined as an overall rate of idle time in the model operation under a decision rule set. Both the failure effect and the idle effect for a decision rule set affected the actual system effectivity and the theoretical system effectivity.

The theoretical system effectivity presented in Chapter 5 was defined as the maximum system utilization rate which was achieved by the model with consideration of the failures. The theoretical system effectivity was determined as follows:

Theoretical system effectivty = 1 - failure effect

In Chapter 5, the theoretical system effectivity should be 0.7526. The failure effect thus becomes 0.2474 under a decision rule set. Recall that a fixed failure time was applied to every decision rule set. This means that the failure effect is also fixed in a decision rule set.

The actual system effectivity for every decision rule set was presented in Table 7-2. The effectivity was an average value of the effectivities for the AS/RS cart, the machine center cell, and the turning cell. The effectivity for the AGVS was not considered for computing the actual system effectivity because no failure data was available.

Each major component's effectivity was determined without consideration of any failure times or idle times. The actual system effectivity was then a maximum utilization rate determined as follows:

Actual system effectivity = 1 - failure effect - idle effect

The theoretical system effectivity should be larger than the actual system effectivity because of the idle effect. When the actual system effectivity is subtracted from the theoretical system effectivity, the idle effect for a decision rule set can be obtained.

Table 7-21 presents the idle effect for each decision rule set. The RANDOM/NINQ rule set had the minimum idle effect because the rule set had the highest actual system effectivity.

7. Model stabilization

As described previously, the master clock of the simulation was set to zero whenever the simulation started evaluating a decision rule set. This means that the model was completely empty except for the seven storage areas in the AS/RS cell. At the initial startup, each of seven storage areas had five different parts as raw materials. There were no parts in process in both the machine center cell and the turning cell. In the actual system, the system would only be empty during the initial startup of the system after construction or following a complete system shutdown. In this research, either of these situations was assumed when the simulation started. The specified simulation run time for each decision rule set was 140 hours in real time. This is sufficient time to observe the performance variation under a decision rule set.

The actual effectivity for each major component was a measure by which model stabilization was determined under a decision rule set. Whenever one of six machine centers completed its processing and released the processed part to the return queue, an intermediate effectivity for both the AS/RS cart and the machine center cell was generated by the CBM computer. When either the robot completed its operation or the robot was idle due to no part presence in the turning cell input queue, an intermediate effectivity for the turning

Table 7-21. Idle effect for a decision rule set

| Set | Decision rule set | Actual system effectivity | Idle effect |
|---|---|---|---|
| 1 | RANDOM/RANDOM | 0.6285 | 0.1241 |
| 2 | RANDOM/FMFS | 0.6235 | 0.1291 |
| 3 | RANDOM/NINQ | 0.6405 | 0.1121 |
| 4 | RANDOM/WINQ | 0.6366 | 0.1160 |
| 5 | FSFS/RANDOM | 0.6262 | 0.1264 |
| 6 | FSFS/FMFS | 0.6384 | 0.1142 |
| 7 | FSFS/NINQ | 0.6373 | 0.1153 |
| 8 | FSFS/WINQ | 0.6320 | 0.1206 |
| 9 | SPT/RANDOM | 0.6207 | 0.1319 |
| 10 | SPT/FMFS | 0.6143 | 0.1383 |
| 11 | SPT/NINQ | 0.6023 | 0.1503 |
| 12 | SPT/WINQ | 0.5912 | 0.1614 |
| 13 | DDATE/RANDOM | 0.6141 | 0.1385 |
| 14 | DDATE/FMFS | 0.6147 | 0.1379 |
| 15 | DDATE/NINQ | 0.6006 | 0.1520 |
| 16 | DDATE/WINQ | 0.5981 | 0.1545 |
| 17 | SLACK/RANDOM | 0.5976 | 0.1550 |
| 18 | SLACK/FMFS | 0.6165 | 0.1361 |
| 19 | SLACK/NINQ | 0.6034 | 0.1492 |
| 20 | SLACK/WINQ | 0.5946 | 0.1580 |
| 21 | S/PT/RANDOM | 0.6107 | 0.1419 |
| 22 | S/PT/FMFS | 0.6100 | 0.1426 |
| 23 | S/PT/NINQ | 0.6140 | 0.1386 |
| 24 | S/PT/WINQ | 0.6105 | 0.1421 |
| 25 | VALUE/RANDOM | 0.6298 | 0.1228 |
| 26 | VALUE/FMFS | 0.6135 | 0.1391 |
| 27 | VALUE/NINQ | 0.6351 | 0.1175 |
| 28 | VALUE/WINQ | 0.6337 | 0.1189 |

Idle effect = Theoretical system effectivity - Actual system effectivity

Theoretical system effectivity = 0.7526

cell was generated by the TRS-80 computer. Because there was no interface between the CBM computer and the TRS-80 computer, the turning cell's effectivity was not combined with the mixed effectivity for the AS/RS cart and the machine center cell. The CBM comuputer did not know when the turning cell started/completed its operations. Each computer generated the intermediate effectivity for its own control component at different points in time.

The actual system effectivity was collected for a decision rule set at the end of the simulation. The effectivity for each major component was also collected at the end of the simulation. This means that the actual effectivity was a maximum effectivity which the model achieved during the simulation. It was assumed that the model stabilized before completion of the simulation. The actual system effectivity was used to determine the model stabilization point under a decision rule set. When the actual system effectivity was divided by the simulation run time for a decision rule set, the average effectivity per minute was obtained. The model was assumed to be stabilized when the effectivity per minute increased to a value equal to the average effectivity per minute obtained at the end of the simulation. This same procedure was applied to the individual components of the model.

The major component's stabilization was achieved under a decision rule set when the average effectivity per minute at time t was greater than or equal to average effectivity per minute at the end of simulation. However, recall that the simulation run time for each decision rule set was adjusted by a time scaling factor for a decision rule set. Therefore, a stabilization time point must be readjusted for consistent comparison with other stabilization time points. This means that each stabilization time point was multiplied by a time scaling factor for each decision rule set. Then, the multiplied stabilization time point thus became real time data.

Table 7-22 presents the time point at which either the AS/RS cart and the machine center cell or the turning cell stabilized under every decision rule set. Each decision rule set is assigned a relative rank for each stabilization time point.

From Table 7-22, the turning cell stabilized earlier than both the AS/RS cart and the machine center cell.

Recall that the actual system effectivity was highly affected by the effectivity for the machine center cell in the correlation coefficient analysis. If a decision rule set had high effectivity for the machine center cell, the rule set also had high value of actual system effectivity. Again, recall that the effectivity for the machine center cell was high if both fetch rate and the processing rate for parts with the long processing time were high under a decision rule set. To determine the effectivity for the machine center cell, the total processing time was used without consideration of the failure time and idle time. The total processing time was high if parts with the long processing time fetched and processed frequently. For an early stabilization time point for both the AS/RS cart and the machine center cell, both the fetch rate and the processing rate for parts with the long processing time must be high under a decision rule set.

Table 7-22. Stabilization point by decision rule set

| Set | Decision rule set | A (effec./min.) | B (hrs.:rank) | C (effec./min.) | D (hrs.:rank) |
|---|---|---|---|---|---|
| 1 | RANDOM/RANDOM | 0.00080 | 10.2778:10 | 0.00114 | 0.6680:7 |
| 2 | RANDOM/FMFS | 0.00080 | 42.8762:20 | 0.00114 | 0.2530:27 |
| 3 | RANDOM/NINQ | 0.00082 | 7.2565:4 | 0.00113 | 1.1744:24 |
| 4 | RANDOM/WINQ | 0.00079 | 8.4775:7 | 0.00112 | 1.1651:23 |
| 5 | FSFS/RANDOM | 0.00079 | 31.3787:13 | 0.00113 | 0.5436:2 |
| 6 | FSFS/FMFS | 0.00082 | 41.8969:17 | 0.00112 | 0.6688:8 |
| 7 | FSFS/NINQ | 0.00081 | 7.9317:6 | 0.00111 | 0.5425:1 |
| 8 | FSFS/WINQ | 0.00078 | 7.6441:5 | 0.00110 | 0.6002:3 |
| 9 | SPT/RANDOM | 0.00075 | 59.5580:27 | 0.00113 | 0.7105:9 |
| 10 | SPT/FMFS | 0.00077 | 38.1218:14 | 0.00113 | 0.7847:21 |
| 11 | SPT/NINQ | 0.00073 | 121.8659:28 | 0.00110 | 0.7766:18 |
| 12 | SPT/WINQ | 0.00069 | 11.5748:12 | 0.00108 | 0.7140:10 |
| 13 | DDATE/RANDOM | 0.00075 | 56.7386:26 | 0.00111 | 0.7806:19 |
| 14 | DDATE/FMFS | 0.00076 | 44.7172:23 | 0.00111 | 0.7845:20 |
| 15 | DDATE/NINQ | 0.00071 | 40.1719:15 | 0.00109 | 1.1759:25 |
| 16 | DDATE/WINQ | 0.00070 | 43.3114:21 | 0.00108 | 0.7705:15 |
| 17 | SLACK/RANDOM | 0.00070 | 46.2890:24 | 0.00109 | 1.2749:28 |
| 18 | SLACK/FMFS | 0.00074 | 42.1958:18 | 0.00111 | 0.7675:12 |
| 19 | SLACK/NINQ | 0.00071 | 53.0302:25 | 0.00107 | 0.7700:14 |
| 20 | SLACK/WINQ | 0.00070 | 42.8051:19 | 0.00108 | 0.7613:11 |
| 21 | S/PT/RANDOM | 0.00073 | 43.9678:22 | 0.00110 | 0.7764:17 |
| 22 | S/PT/FMFS | 0.00075 | 40.4971:16 | 0.00110 | 0.7749:16 |
| 23 | S/PT/NINQ | 0.00073 | 10.4838:11 | 0.00110 | 0.7685:13 |
| 24 | S/PT/WINQ | 0.00071 | 9.9107:9 | 0.00108 | 1.1572:22 |
| 25 | VALUE/RANDOM | 0.00080 | 6.4847:3 | 0.00113 | 1.1773:26 |
| 26 | VALUE/FMFS | 0.00077 | 8.7308:8 | 0.00113 | 0.6093:5 |
| 27 | VALUE/NINQ | 0.00080 | 4.8902:1 | 0.00111 | 0.6011:4 |
| 28 | VALUE/WINQ | 0.00079 | 5.1692:2 | 0.00109 | 0.6585:6 |

A = Average effectivity/minute for both the AS/RS cart and the machine center.
B = Stabilization time point readjusted by a time scaling factor for both the AS/RS cart and the machine center cell.
C = Average effectivity/minute for the turning cell.
D = Stabilization time point readjusted by a time scaling factor for the turning cell.

If the model generated more available spaces for fetched parts under a machine center selection rule, the model usually stabilized early. Generally, the rules NINQ and WINQ generated more spaces than the rules RANDOM and FMFS.

Whenever the turning cell had a part on its input queue, the turning cell stabilized. This is why this cell stabilized much quicker than the AS/RS cart and the machine center cell.

The simulation data collected for each of twenty-eight decision rule sets and the analysis procedure for the data have been presented in this chapter. These data must be evaluate to determine which decision rule sets should be used in practice. This evaluation is the subject of the following chapter.

# VIII. SIMULATION RESULTS

## A. Introduction

Of the twenty-eight decision rule sets evaluated, those performing best should have the following performance features under a fixed failure effect:

- High actual system effectivity;
- Low traveling time;
- High production output;
- Low manufacturing throughput time;
- Low work-in-process inventory;
- Low production lateness.

In this chapter, the best decision rule sets for the FMS model are evaluated using the above criteria. Both the best and the worst performers are illustrated in relation to each performance criterion.

## B. Best and Worst Decision Rule Sets

The best decision rule sets can be selected from the simulation results presented in Chapter 7. Table 8-1 presents both the best decision rule sets and the worst decision rule sets on the basis of various performance criteria. There is no decision rule set which was the best one for all performance criteria. Under each performance criterion, a specific decision rule set was the best or the worst set. The implications of these results are described in greater detail in the sections that follow.

Table 8-1. Best and worst decision rule sets

| Performance criterion | Best | Worst |
|---|---|---|
| actual system effectivity | RANDOM/NINQ (0.6405) | SPT/NINQ (0.5912) |
| relative system effectivity | RANDOM/NINQ (0.8510) | SPT/WINQ (0.7855) |
| total travelling time (hrs.) | SLACK/RANDOM (100.0296) | RANDOM/RANDOM (111.9045) |
| average travelling time (hrs./part) | S/PT/WINQ (0.1051) | RANDOM/RANDOM (0.1179) |
| actual production output (parts) | SPT/NINQ (739) | VALUE/FMFS (622) |
| achievement rate | SLACK/WINQ (0.7335) | SPT/FMFS (0.6849) |
| total throughput time (hrs.) | SPT/WINQ (4051.8839) | S/PT/NINQ (4754.1233) |
| average throughput time (hrs./part) | SPT/WINQ (5.5429) | VALUE/FMFS (7.5999) |
| work remaining (hrs.) | SLACK/WINQ (11.2500) | SLACK/RANDOM (29.0167) |
| imminent operation work content (hrs.) | SLACK/RANDOM (5.4100) | RANDOM/RANDOM (10.8666) |
| total waiting time (hrs.) | SLACK/WINQ (568.7459) | VALUE/FMFS (2947.9559) |
| average waiting time (hrs./part) | SLACK/WINQ (0.8137) | VALUE/FMFS (4.7359) |
| total production lateness (hrs.) | VALUE/WINQ (- 1025.0576) | DDATE/NINQ (- 31.8666) |
| average production lateness (hrs./part) | VALUE/WINQ (- 1.5461) | DDATE/NINQ (- 0.0444) |

## C. Actual System Effectivity

### 1. Overview

From the equation for the actual system effectivity, a decision rule set should have the following features to have high actual system effectivity:

- For the AS/RS cart, the fetch rate for the most distant storage area (storage area 7) should be high.
- For the machine center cell, both the fetch rate and the processing rate for parts with the longest processing time (part family 6) should be high;
- For the turning cell, the fetch rate should be high.

Under this performance criterion, the RANDOM/NINQ rule set was the best performer (0.6405). The SPT/WINQ rule set was the worst performer (0.5912). These same rule sets also performed best and worst on the basis of relative system effectivity.

According to the correlation coefficient analysis, the actual system effectivity was high if the effectivity for the machine center cell was high (r= 0.9606 in Table 7-14). Also, the actual system effectivity had a strong relationship with the average production lateness per part (r= -0.9086) in Table 7-14.

### 2. RANDOM/NINQ rule set

On the basis of system effectivity, this rule set was the best performer. Under the rule set, the effectivities for the AS/RS cart, the machine center cell and the turning cell were 0.4958, 0.6399 and 0.7858 respectively. The effectivity for the AS/RS cart was the highest value obtained for all decision rule sets. The effectivity for the machine center cell was the 7th highest value. The effectivity for the turning cell was the 8th highest value obtained.

This rule set had the following operating features:

- From Table 7-15, the fetch rate for storage area 7 was the highest value obtained. The fetch rate for storage area 1 ranked 23rd;
- From Table 7-17a, the fetch rate for part family 6 was the 6th highest. The fetch rate for part family 4 ranked 17th;
- From Table 7-17b, the fetch rate for parts routed to the machine center cell ranked 15th. The fetch rate for the turning cell ranked 14th;
- From Table 7-19, the processing rate for part family 6 ranked the 6th highest, and the rate for part family 4 ranked 18th.

3. SPT/WINQ rule set

On the basis of system effectivity, this decision rule set was the worst performer. Under this rule set, the effectivities for the AS/RS cart, the machine center cell and the turning cell were 0.4773, 0.5167, and 0.7797 respectively. The effectivity for the AS/RS cart was 7th highest obtained. The effectivity for the machine center cell was the lowest value obtained and ranked 28th. The effectivity for the turning cell ranked 19th.

This rule set had the following operating features:

- From Table 7-15, the fetch rates for storage areas 2 and 7 were the lowest values obtained. However, the fetch rates for storage areas 1, 4 and 5 were the highest values obtained;
- From Table 7-17a, the fetch rates for part families 6 and 2 were the lowest. The fetch rate for part family 4 was the 2nd highest;

- From Table 7-17b, the fetch rate for parts routed to the machine center cell was the 2nd highest. The fetch rate for parts to routed to the turning cell ranked 27th.
- From Table 7-19, the processing rate for part family 6 was the lowest. The processing rate for part family was the 2nd highest value.

4. Other decision rule sets

As described previously, if the fetch rate for storage area 7 was the highest value in a decision rule set, the AS/RS cart effectivity tended to be high. The RANDOM/NINQ rule set had the highest fetch rate for storage area 7 in Table 7-15. This rule set had also the highest AS/RS cart effectivity in Table 7-2. The RANDOM/NINQ rule set was the best performer on the basis of actual system effectivity.

If the fetch rate for part family 6 with the longest processing time was the highest value in a decision rule set, the effectivity for the machine center cell tended to be high. The FSFS/FMFS rule set had the highest fetch rate for part family 6 in Table 7-17a. This rule set had 3rd highest effectivity for the machine center cell in Table 7-2. On the basis of actual system effectivity, the FSFS/FMFS rule set was the 2nd best performer. (See Table 7-2.)

If the fetch rate for parts routed to the turning cell was the highest value in a decision rule set, the effectivity for the turning cell tended to be high. The SLACK/FMFS rule set had the highest fetch rate for the parts in Table 7-17b. This rule set had 4th highest effectivity for the turning cell. On the basis of actual system effectivity, the SLACK/FMFS rule set ranked 13th in Table 7-2.

5. Relationship with average production lateness

From the correlation coefficient analysis for the performance criteria, the actual system effectivity had an inverse linear relationship with the average production lateness per part (r= -0.9086 in Table 7-14). This means that a decision rule set had low average production lateness (high earliness) when the rule set had high actual system effectivity or vice versa. All decision rule sets presented negative values of the average production lateness.

The RANDOM/WINQ rule set was the best performer on the basis of actual system effectivity. It ranked 7th (-1.2744 hrs./part) on the basis of average production lateness. (See Table 7-12.) The SPT/WINQ rule set was the worst performer on the basis of system effectivity. This rule set ranked 16th (-0.7280 hrs./part) on the basis of average production lateness.

The VALUE/WINQ rule set ranked 6th on the basis of actual system effectivity. This rule set was the best performer on the basis of average production lateness per part.

6. Summary

A decision rule set with high actual system effectivity had high relative system effectivity. The ranks of decision rule sets were identical for both criteria. A decision rule set generally had the following features for high system effectivity:

- High fetch rate for parts with long processing times;
- High processing rate for parts with long processing times;
- High effectivity for the machine center cell;
- High relative system effectivity;
- Low average production lateness per part.

## D. Traveling Time

### 1. Overview

Total traveling time was determined by total fetch time and total route time. Average traveling time per part was determined by the total traveling time divided by the total number of fetches. In this research, either minimum total traveling time or minimum average traveling per part is desirable to reduce the manufacturing throughput time of a part. A decision rule set has the minimum values of either the total traveling time or the average traveling time per part when the rule set satisfies the following conditions:

- Minimum value of total fetch time;
- Minimum value of total route time.

The total traveling time under a decision rule set did not include any failure time, and idle time of the AS/RS cart, or delays such as DELAY-1, DELAY-2, and normalization delay. From the correlation coefficient analysis, this criterion did not have any significant relationship with other performance criteria.

The SLACK/RANDOM rule set had the minimum value of the total traveling time (100.0296 hrs.) in Table 7-5. The S/PT/WINQ rule set had the minimum value of the average traveling time per part (0.1051 hrs./part) in Table 7-6. The RANDOM/RANDOM rule set had the maximum value of both the total traveling time (111.9045 hrs.) and the average traveling time per part (0.1179 hrs./part).

The FSFS/FMFS rule set was introduced to reduce the traveling time of a part. The nearest storage area from the AS/RS cart's starting position was selected by the FSFS part selection rule. The nearest machine center from the AS/RS cell was selected for a fetched part by the FMFS machine center selection rule.

The FSFS/FMFS rule set ranked 22nd in the total traveling time and 23rd in average traveling time per part. This means that the traveling time of a part was highly dependent upon the part distribution in the seven storage areas in every fetch. Also, the traveling time was dependent upon the maximum queue length of a machine center. If storage area 1 did not have any available parts, the AS/RS cart had to travel to the other storage areas to fetch the desired part. If machine center 1 was full with five parts, a fetched part was routed to a more distant machine center having an available space.

2. SLACK/RANDOM rule set

On the basis of total traveling time, this decision rule set performed best. For this rule set, the total fetch time in real time was the 2nd lowest value (63.6124 hrs.). The total route time was also the 2nd lowest value (36.4172 hrs.) (See Table 7-5b.). The total number of fetches for parts was the lowest value obtained as shown in Table 7-7. The average traveling time per part ranked 3rd (0.1066 hrs./part) in Table 7-6.

3. S/PT/WINQ rule set

The total fetch time and the total route time ranked 4th (64.4943 hrs.) and 6th value (36.8022 hrs.) respectively in Table 7-5b. The total traveling time ranked 6th (101.2965 hrs.). The total number of fetches for parts ranked 4th in Table 7-7. Due to the low total traveling time and high total number of fetches, the rule set ranked first on the basis of average traveling time per part.

4. RANDOM/RANDOM rule set

The total fetch time and the total route time ranked 25th and 28th respectively in Table 7-5b. The total number of fetches for parts ranked 18th. This rule set performed the worst on the basis of average traveling time per part.

5. Summary

A decision rule set had low values of total travelling time when both the total fetch time and the total route time in real time were small. To have a small average traveling time per part, a decision rule set had to have a large total number of fetches for parts.

## E. Actual Production Output

1. Overview

The actual production output was defined as number of parts produced by the FMS model under a decision rule set with failures of major system components. The achievement rate was determined by the actual production output divided by the total number of fetches. The achievement rate was considered as the productivity of the FMS model.

For a high value of actual production output, the model had to generate more available spaces for fetched parts on either the machine center cell or the turning cell under a decision rule set. For a high achievement rate, a decision rule set had to demonstrate both high production output and a low number of fetches.

According to the correlation coefficient analysis, this performance criterion had a significant relationship with both average throughput time per part (r= -0.9306) and average waiting time per part (r= -0.8306).

Under the SPT/NINQ rule set, the model produced the highest number of parts (739 parts). The model produced the lowest number of parts under the VALUE/FMFS rule set. For the achievement rate, the SLACK/NINQ rule set had the highest value (0.7335). The SPT/FMFS rule set had the lowest value (0.6849).

2. SPT/NINQ rule set

The SPT/NINQ rule set had the highest production output and demonstrated the following operating features:

- From Table 7-7, total number of fetches for parts was the highest obtained (1020 parts). The achievement rate ranked 4th (0.7245);
- From Table 7-17a, the fetch rate for part family 4 with the shortest processing time was the highest obtained. For part family 6 with the longest processing time, the fetch rate ranked 25th;
- From Table 7-17b, the fetch rate for parts routed to the machine center cell was the highest obtained. Among twenty-eight decision rule sets, this rule set generated the highest number of spaces on the machine center cell;
- From Table 7-19, the processing rate for part family 4 was the highest obtained. The rate for part family 6 ranked 27th.

3. VALUE/FMFS rule set

This rule set had the lowest value of actual production output. It demonstrated the following operating features:

- From Table 7-7, total number of fetches for parts ranked 27th (903 parts). The achievement rate ranked 25th (0.6888);
- From Table 7-17a, the fetch rate for part family 4 ranked 25th, and the rate for part family 6 ranked 5th;
- From Table 7-17b, the fetch rate for parts routed to the machine center cell ranked 26th;
- From Table 7-19, the processing rate for part family 4 ranked 24th, and the rate for part family 6 ranked 3rd.

4. SLACK/WINQ rule set

This rule set had the highest value of achievement rate and demonstrated the following operating features:

- From Table 7-7, total number of fetches for parts ranked 15th (953 parts). The actual production output ranked 4th (699 parts);
- From Table 7-17a, the fetch rate for part family 4 ranked 5th, and the rate for part family 6 ranked 25th;
- From Table 7-17b, the fetch rate for parts routed to the machine center cell ranked 3rd;
- From Table 7-19, the processing rate for part family 4 ranked 5th. The rate for part family 6 ranked 25th.

5. SPT/FMFS rule set

This rule set had the lowest value achievement rate and demonstrated the following features:

- From Table 7-7, total number of fetches for parts ranked 26th (914 parts). The actual production output ranked 27th (626 parts);

- From Table 7-17a, the fetch rate for part family 4 ranked 19th. The rate for part family 6 ranked 9th;
- From Table 7-17b, the fetch rate for parts routed to the machine center cell ranked 25th;
- From Table 7-19, the processing rate for part family 4 ranked 19th. The rate for part family 6 ranked 8th.

6. Relationship with total number of fetches

The correlation between the actual production output and the total number of fetches for parts was 0.9409 in Table 7-14. This means that the FMS model manufactured more parts if a decision rule set had a higher number of fetches. For example, the SPT/NINQ rule set yielded the highest values in both the actual production output and the total number of fetches.

7. Relationship with average throughput time per part

From the correlation coefficient analysis, the actual production output had an inverse linear relationship with average throughput time per part (r= -0.9306 in Table 7-14). This means that a decision rule set generally had a low value of average throughput time per part when the rule set had high production output. For example, the SPT/NINQ rule set yielded the 2nd lowest value of the average throughput time per part.

8. Relationship with average waiting time per part

Average waiting time per part was an additional measure of work-in-process inventory under a decision rule set. The average waiting time was defined as an average amount of time for a part to wait in a machine center queue for processing.

From Table 7-14, the correlation between the actual production output and the average waiting time per part was -0.8306. This means that a decision rule set generally had low value of the average waiting time per part when the FMS model manufactured a large number of parts under the rule set. For example, the SPT/NINQ rule set ranked 4th in terms of the average waiting time per part. The SLACK/WINQ rule set which had the highest value of the achievement rate had the lowest value of the average waiting time per part.

## 9. Summary

If the machine center cell generated more spaces for fetched parts under a decision rule set, the rule set showed better performance. When the fetch rate for parts with the short processing time was high, both the actual production output and the achievement rate were high. Also, the best decision rule sets consisted of either NINQ rule or WINQ rule as a machine center selection rule. This means that the NINQ and WINQ rules dominated the RANDOM and FMFS rules for generating more spaces on the machine center cell.

A decision rule set which had high values of both the actual production output and achievement rate generally had the following features:

- The total number of fetches for parts was large;
- The fetch rate for parts with the short processing times was high;
- The processing rate for parts with the short processing times was high;
- The fetch rate for parts routed to the machine center cell was high;
- The average throughput time per part was low;
- The average waiting time per part was low.

## F. Manufacturing Throughput Time

### 1. Overview

The throughput time was defined as a total amount of time required for a part to be manufactured by the FMS model. This time factor includes processing times, failure times and idle times for major components, and delays such as DELAY-1, DELAY-2 and the normalization delay in fetching operation. Average throughput time per part was determined by total throughput time divided by the actual production output under a decision rule set.

According to the equation for total throughput time in Chapter 5, a decision rule set had to demonstrate the following operating features to have small amount of throughput time.

- Small amount of idle time. It should be noted that failure times of each major component, DELAY-1, DELAY-2, normalization delay were fixed in each decision rule set;
- Both fetch rate and processing rate for parts with the short processing time had to be high. This permitted the machine center cell to generate more spaces for parts;
- High value of actual production output.

For the total throughput time, the SPT/WINQ rule set was the best performer (4051.8839 hrs.). The S/PT/NINQ rule set was the worst performer (4754.1233 hrs.). For average throughput time per part, the SPT/WINQ rule set was the best performer (5.5429 hrs/part). The VALUE/FMFS rule set was the worst performer (7.5991 hrs/part). From the correlation coefficient analysis, the average throughput time per part had a strong inverse relationship with the actual production output (r= -0.9306)

2. SPT/WINQ rule set

This rule set was the best performer in terms of both total throughput time and average throughput time per part. This rule set demonstrated the following operating features:

- From Table 7-7, the rule set had the 2nd highest values of both the actual production output and the total number of fetches for parts;
- From Table 7-17a, the fetch rate for part family 4 was the 2nd highest value. The rate for part family 6 was the lowest value obtained;
- From Table 7-17b, the fetch rate for parts routed to the machine center cell was the 2nd highest value;
- From Table 7-19, the processing rate for part family 4 was the 2nd highest value. The rate for part family 6 was the lowest value obtained.

3. S/PT/WINQ rule set

This decision rule set was the worst performer on the basis of total throughput time with the following operating features:

- From Table 7-7, the rule set ranked 11th and 14th for the total number of fetches and the actual production output respectively. The average throughput time per part ranked 16th under this decision rule set;
- From Table 7-17a, the fetch rate for part family 4 ranked 10th, and the rate for part family 6 ranked 20th;
- From Table 7-17b, the fetch rate for parts routed to the machine center cell ranked 21st;
- From Table 7-19, the processing rate for part family 4 ranked 10th, and the rate for part family 6 ranked 20th.

4. VALUE/FMFS rule set

This rule set was the worst performer on the basis of average throughput time per part with the following operating features:

. From Table 7-7, the rule set yielded the lowest values for both the total number of fetches and the actual production output;

. From Table 7-17a, the fetch rate for part family 4 ranked 25th, and the rate for part family 6 ranked 5th;

. From Table 7-17b, the fetch rate for parts routed to the machine center cell ranked 26th;

. From Table 7-19, the processing rate for part family 4 ranked 24th, and the rate for part family 6 ranked 3rd.

5. Relationship with actual production output

From Table 7-14, the correlation between the average throughput time per part and the actual production output was -0.9306. This means that a decision rule set generally had high production output when the rule set had low value of average throughhput time per part. For example, the SPT/WINQ rule set had 2nd highest value of the actual production output in Table 7-7. The SPT/NINQ rule set which was the best performer under the actual production output criterion had the 2nd lowest value of average throughput time per part.

6. Summary

A decision rule set generally yielded a low value of the throughput time when the following conditions were satisfied:

. High fetch rate for the machine center cell;
. High fetch rate for parts with short processing times;
. High processing rate for parts with short processing times;
. High actual production output.

## G. Work-In-Process Inventory

### 1. Overview

As stated in Chapter 7, there were four different measures for work-in-process inventory under a decision rule set: work remaining, imminent operation work content, total waiting time, and average waiting time per part. Both the work remaining and the imminent operation work content were measured at the end of simulation for a decision rule set. Total waiting time was the cumulative waiting time for all processed parts on the machine center cell during the simulation. The average waiting time per part was determined by the total waiting time divided by the actual production output.

At the end of each simulation, each decision rule set yielded a specific part sequence on the machine center cell and the turning cell. Table 8-2 presents the part sequence at the end of simulation for each decision rule set. The final part sequence was used to obtain the work remaining and the imminent operation work content. The work remaining was the sum of processing times of all parts on all machine centers and the turning cell under a decision rule set. The left-hand number in each box is the very next part to be processed by a machine center or the turning cell. The imminent operation work content was the sum of processing times of all left-hand entries under a decision rule set. From Table 8-2, all decision rule sets except the DDATAE/ NINQ and the SLACK/WINQ rule sets had almost full waiting lines in the machine center cell.

For a small amount of the work-in-process inventory, either the machine center or the turning cell had to generate a large number of

Table 8-2. Final part sequence for decision rule sets

| Set | Decision rule set | Machine center 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| 1 | RANDOM/RANDOM | 1,4,4,7 | 2,1,3 | 6,1,5,1,6 | 6,7,7,4,4 |
| 2 | RANDOM/FMFS | 3,5,4,6 | 6,4,4,6,5 | 7,6,7,7,4 | 7,7,5,2,5 |
| 3 | RANDOM/NINQ | 6,4,7,4,6 | 6,1,1,2,7 | 7,4,2,7,7 | 3,5,3,2 |
| 4 | RANDOM/WINQ | 7,4,2,6 | 6,7,4,5,4 | 5,7,6,1 | 6,7,3,3 |
| 5 | FSFS/RANDOM | 6,6,1,2,7 | 4,3 | 2,6,4,2,5 | 2,7,1,7,4 |
| 6 | FSFS/FMFS | 5,7,3,3,3 | 4,5,1,4,5 | 7,2,3,2 | 6,7,4,6,7 |
| 7 | FSFS/NINQ | 1,7,4,7,1 | 6,6,4,5 | 2,7,3,1,4 | 2,5,4,1,2 |
| 8 | FSFS/WINQ | 6,2,5,6,1 | 6,4,7,2,7 | 2,5,5,3,3 | 1,4,4,3,6 |
| 9 | SPT/RANDOM | 3,5,3,2,6 | 7,4,6,3,4 | 6,2,4,5,2 | 2,5,4,7 |
| 10 | SPT/FMFS | 1,5,6,5,4 | 6,2,3,7,2 | 1,6,4,2,1 | 7,3,1,1,3 |
| 11 | SPT/NINQ | 1,6,4 | 7,1,4,2 | 6,2,7,2,3 | 3,3,6,7,2 |
| 12 | SPT/WINQ | 5,1,4,4,7 | 2,3,2,4 | 6,5,3 | 2,1,1,1 |
| 13 | DDATE/RANDOM | 3,4,5,4,6 | 6,1,1,3,6 | 2,7,5,2 | 1,3,7,2 |
| 14 | DDATE/FMFS | 1,7,6,4,7 | 4,4,1,6 | 6,3,4,2 | 1,7,3,2 |
| 15 | DDATE/NINQ | 2,7,6 | 2,2 | 2,1,7 | 6,3,7 |
| 16 | DDATE/WINQ | 2,4,1,7 | 6,3 | 6,7,2 | 4,3,2,6 |
| 17 | SLACK/RANDOM | 3,7,2,4,7 | 5,1,2,6 | 6,6,1,2 | 1,4,2 |
| 18 | SLACK/FMFS | 3,5,6,6,7 | 6,7,6,7,3 | 2,3,5,4,2 | 4,7,6,2 |
| 19 | SLACK/NINQ | 6,7,5,7,1 | 4,5,4,3 | 2,1,4,6,6 | 4,7,5,2 |
| 20 | SLACK/WINQ | 4 | 2 | 7,2 | 3,4,6 |
| 21 | S/PT/RANDOM | 6,3,6,2,4 | 1,3,4,7 | 2,7,6,6,2 | 1,5,2,1,1 |
| 22 | S/PT/FMFS | 5,1,7,4 | 3,6,2,7,7 | 2,2,6,7,6 | 2,4 |
| 23 | S/PT/NINQ | 6,1,2,5,6 | 2,4,1,7,6 | 6,7,2,4 | 7,4,6,3 |
| 24 | S/PT/WINQ | 1,6,7,4,5 | 5,2,4,2 | 2,4,7,4,3 | 7,1,6,1 |
| 25 | VALUE/RANDOM | 1,2,7,2 | 3,1,7,2 | 6,7,7,4 | 6,4,6,2,2 |
| 26 | VALUE/FMFS | 2,7,2,7 | 2,1,5,4,5 | 7,7,4,6 | 3,2,3,5 |
| 27 | VALUE/NINQ | 7,1,7,7,6 | 2,6,1,3,7 | 1,5,5,2 | 4,6,4,4 |
| 28 | VALUE/WINQ | 3,5,6,4,7 | 1,2,4,2 | 4,7,6,7 | 2,1,1,6 |

Table 8-2. (continued)

| Set | Decision rule set | Machine center 5 | Machine center 6 | Turning cell |
|---|---|---|---|---|
| 1 | RANDOM/RANDOM | 6,6,3,3,2 | 7,2,7,2 | 5,5,3,3,5 |
| 2 | RANDOM/FMFS | 2,2,5 | 2,1,2 | 3,3,1,1,3 |
| 3 | RANDOM/NINQ | 6,2,1,4,1 | 5,3,3,6,4 | 5,5 |
| 4 | RANDOM/WINQ | 4,2,6,2 | 3,2,1,1,2 | 1,5,5,3,3 |
| 5 | FSFS/RANDOM | 3,5,7,7 | 6,1,6,1,2 | 5,1,3,5,3 |
| 6 | FSFS/FMFS | 1,5,2,4,6 | 2,6,4,3,7 | 1,1 |
| 7 | FSFS/NINQ | 2,6,3,7 | 6,5,4,5,6 | 3,3,1 |
| 8 | FSFS/WINQ | 7,3,5,4,2 | 1,6,1,2,4 | 1 |
| 9 | SPT/RANDOM | 1,1,6,7 | 5,2,7,5,4 | 1,3,1 |
| 10 | SPT/FMFS | 6,7,2,5,7 | 6,4,4,4,5 | 3 |
| 11 | SPT/NINQ | 2,3,1,6 | 5,4,4,6,7 | 5,3,5,5 |
| 12 | SPT/WINQ | 4,3,7 | 7,6,5 | 3,5 |
| 13 | DDATE/RANDOM | 6,7,4,2,2 | 1,5,7,4,6 | 3,5,3 |
| 14 | DDATE/FMFS | 6,2,2,7,6 | 3,5,1,4 | 5,5,5,1,3 |
| 15 | DDATE/NINQ | 1,7 | 1 | 3,3,1,3 |
| 16 | DDATE/WINQ | 4,3,3,5,4 | 7,1,2 | 1,5,1,5 |
| 17 | SLACK/RANDOM | 1,1,3,6,7 | 4,2,4,7,6 | 5,5,5,3,3 |
| 18 | SLACK/FMFS | 2,4,3,1 | 1,7,5 | 1,5,1,5,3 |
| 19 | SLACK/NINQ | 2,7,5,6 | 6,2,1,3,2 | 3,5,3,1 |
| 20 | SLACK/WINQ | 3 | 6 | 1,3,5,3,3 |
| 21 | S/PT/RANDOM | 4,5,4,6 | 2,7,7,3,7 | 1,5 |
| 22 | S/PT/FMFS | 6,3,4,3,5 | 7,2,6 | 3,1,5,5,5 |
| 23 | S/PT/NINQ | 1,4,2 | 2,7,3 | 5,3,1,5,5 |
| 24 | S/PT/WINQ | 2,5,7,6 | 6,3,5,4,3 | 3,3,1 |
| 25 | VALUE/RANDOM | 4,5,3,7,4 | 5,3,1,1,6 | 3,5,3,5 |
| 26 | VALUE/FMFS | 6,4,3,7,4 | 2,1,6,6 | 3,1,5,1,1 |
| 27 | VALUE/NINQ | 4,2,2,1 | 6,6,4,5 | 3,3,3,1,3 |
| 28 | VALUE/WINQ | 6,7,3,4,4 | 5,5,6,2 | 1,3,1,5,3 |

spaces for fetched parts. This means that a large number of machine centers which have short queues or the small amounts of work in queue will result in small work-in-process inventory. For the turning cell, a short queue is also desirable. When the fetch rate for parts with short processing times is high, more available spaces for fetched parts can be generated.

From the correlation coefficient analysis, both the work remaining and the imminent operation work content measures had no significant relationships with other performance criteria. However, the average waiting time per part had a significant relationship with the actual production output.

Under the work remaining measure in Table 7-10, the SLACK/WINQ rule set was the best performer, and the SLACK/RANDOM rule set was the worst performer. However, under the imminent operation work content measure in Table 7-10, the SLACK/RANDOM rule set was the best performer, and the RANDOM/RANDOM rule set was the worst performer.

Under the total waiting time measure in Table 7-11, the SLACK/WINQ rule set was the best performer, and the VALUE/FMFS rule set was the worst performer. For the average waiting time measure in Table 7-11, the SLACK/WINQ rule set was the best performer, and the VALUE/FMFS rule set was the worst performer.

## 2. SLACK/WINQ rule set

This decision rule set was performed very well in relation to the work-in-process inventory criterion. This set was the best performer in the work remaining measure, the total waiting time and the average waiting time per part. Under the imminent operation work content measure, this rule set was the 2nd best performer. The following features were demonstrated by the SLACK/WINQ rule set:

- From Table 7-7, the total number of fetches for parts ranked 15th. The actual production output ranked 4th. The achievement rate was the best obtained;
- From Table 7-17a, the fetch rate for part family 4 ranked 5th. The rate for part family 6 ranked 25th;

- From Table 7-17b, the fetch rate for parts routed to the machine center cell ranked 3rd;
- From Table 7-19, the processing rate for part family 4 ranked 5th, and the rate for part family 6 ranked 25th;
- From Table 8-2, the least number of parts awaited for processing on the machine center cell at the end of the simulation.

3. SLACK/RANDOM rule set

This decision rule set was the worst performer under the work remaining measure. The rule set was the best performer under the imminent operation work content measure. The following features were observed:

- From Table 7-7, the total number of fetches for parts ranked 23rd. The actual production output ranked 22nd. The achievement rate ranked 23rd;
- From Table 7-17a, the fetch rate for part family 4 ranked 7th. The rate for part family 6 ranked 22nd;
- From Table 7-17b, the fetch rate for parts routed to the machine center cell ranked 23rd;
- From Table 7-19, the processing rate for part family 4 ranked 7th. The rate for part family 6 ranked 22nd;
- From Table 8-2, each machine center was busy with three or more parts. However, the very next part to be processed by each machine center was a part with a short processing time at the end of the simulation;
- From Table 7-11, the total waiting time ranked 11th. The average waiting time per part ranked 14th.

4. RANDOM/RANDOM rule set

This decision rule set was the worst performer under the imminent operation work content measure. The following features were observed:

- From Table 7-7, the total number of fetches for parts ranked 18th. The actual production output ranked 19th. The achievement rate ranked 15th;
- From Table 7-17a, the fetch rate for part family 4 ranked 12th. The rate for part family 6 ranked 11th;
- From Table 7-17b, the fetch rate for parts routed to the machine center cell ranked 22nd;
- From Table 7-19, the processing rate for part family 4 ranked 12th. The rate for part family 6 ranked 11th;
- From Table 8-2, the very next part to be processed by each machine center was a part with a long processing time at the end of the simulation;
- From Table 7-11, the total waiting time and the average waiting time per part both ranked 20th.

## 5. VALUE/FMFS rule set

This decision rule set was the worst performer under both the total waiting time and the average waiting time per part. The following features were observed:

- From Table 7-7, the total number of fetches for parts ranked 27th. The actual production output was the lowest value obtained. The achievement rate ranked 25th;
- From Table 7-17a, the fetch rate for part family 4 ranked 25th. The rate for part family 6 ranked 5th;
- From Table 7-17b, the fetch rate for parts routed to the machine center cell ranked 26th;
- From Table 7-19, the processing rate for part family 4 ranked 24th. The rate for part family 6 ranked 3rd;
- From Table 8-2, each machine center was busy with more than four parts at the end of the simulation;
- From Table 7-10, the work remaining ranked 7th. The imminent operation work content ranked 16th.

6. Average waiting time and actual production output

From the correlation analysis, the average waiting time per part had an inverse linear relationship with the actual production output ($r = -0.8306$). This means that a decision rule set generally had a small amount of the average waiting time if the rule set had high production output. As result, the SLACK/WINQ rule set ranked 4th in actual production output. The VALUE/FMFS rule set ranked 28th in the actual production output. The SPT/NINQ rule set had the highest value of the actual production output. It ranked 4th in average waiting time per part.

7. Summary

A decision rule set generally had low work-in-process inventory when the following conditions existed:

- A large number of machine centers had either low amounts of work in queue or the short queues throughout the simulation;
- High fetch rate and high processing rate for parts with the short processing times were observed frequently;
- High actual production output was observed.

## H. Production Lateness

1. Overview

The production lateness was defined as difference between completion time and due-date of a part. The completion time includes processing time, failure times and idle time of major components. It also includes delays such as DELAY-1, DELAY-2 and the normalization delay in every fetch and arrival time of a part. The due-date was determined by arrival time plus TWK allowance of a part. This has been presented in Chapter 5.

The average production lateness per part was determined by the total production lateness divided by the actual production output under a decision rule set. According to the equation for the production lateness in Chapter 5, a decision rule set had to demonstrate the following operating features to have low production lateness. The reader should recall that negative production lateness means production earliness.

- Small amounts of idle time. Recall that failure times, DELAY-1 and DELAY-2 were fixed in each simulation;
- Either high fetch rate for parts with the short processing time or high fetch rate for parts with the long processing time. High fetch rates for parts with the short processing times can be expected to result in small completion times. On the other hand, the high fetch rate for parts with the long processing time can be expected to result in high due-date values. Part family 4 had the smallest due-date, and part family 6 had the largest due-date.

From Table 7-12, every decision rule set generated negative production lateness values (earliness). The best performer was the VALUE/WINQ rule set under total production lateness. The worst performer was the DDATE/NINQ rule set. Under the average production lateness per part, the VALUE/WINQ rule set was also the best performer, and the DDATE/NINQ rule set was the worst performer. From the correlation coefficient analysis, the average production lateness per part had an inverse relationship with the actual system effectivity.

2. VALUE/WINQ rule set

Under both the total production lateness and average production lateness, this decision rule set was the best performer. It demonstrated the following features:

- From Table 7-7, the total number of fetches for parts ranked 21st. The actual production output ranked 18th;
- From Table 7-17a, the fetch rate for part family 4 was the lowest value obtained. The rate for part family 6 ranked 2nd;
- From Table 7-17b, the fetch rate for parts routed to the machine center cell ranked 11th;
- From Table 7-19, the processing rate for part family 4 was the lowest value obtained. The rate for part family 6 ranked 4th.

3. DDATE/WINQ rule set

This decision rule set was the worst performer under both total production lateness and the average production lateness. The following operating features were observed:

- From Table 7-7, the total number of fetches for parts ranked 3rd. The actual production output ranked 3rd, also;
- From Table 7-17a, the fetch rate for part family 4 ranked 3rd. The rate for part family 6 ranked 27th;
- From Table 7-17b, the fetch rate for parts routed to the machine center cell ranked 6th;
- From Table 7-19, the processing rate for part family 4 ranked 3rd. The rate for part family 6 ranked 26th.

4. Relationship with actual system effectivity

According to Table 7-14, the correlation coefficient was -0.9086 between the average production lateness per part and the actual system effectivity. This means that a decision rule set generally had high actual system effectivity when the rule set had a low value of average production lateness per part. As a result, the VALUE/WINQ rule set ranked 6th in the actual system effectivity. The DDATE/NINQ rule set ranked 24th. The RANDOM/NINQ rule set which was the best performer under actual system effectivity criterion ranked 7th on the basis of average production lateness per part.

### 5. Summary

A decision rule set had low production lateness (a large negative value) when the following features were satisfied:

- High fetch rate and high processing rate for parts with the long processing times. This means that a large due-date value is desirable in obtaining low production lateness;
- High actual system effectivity.

## I. Overall Features

### 1. Performance criteria

All of the best decision rule sets for the six performance criteria have been presented and analyzed in the previous sections. In general, the performance criteria can be classified into two groups using both the fetch rate and the processing rate. The first group includes the actual system effectivity and the production lateness. The second group includes the actual production output, manufacturing throughput time and work-in-process inventory. The traveling time can be included in either group.

For the first group, both the fetch rate and the processing rate for parts with long processing times were a principal factor in determining the good performance of a decision rule set. For the second group, both the fetch rate and the processing rate for parts with short processing times were a principal factor in determining the decision rule sets that performed well.

There were no "best" decision rule sets which can be included in both groups. That is, if a decision rule set showed good performance for the first group of performance criteria, then that same rule set demonstrated poor performance under the second group of performance criteria. Both groups were therefore evaluated to find good as opposed to optimal decision rule sets that demonstrated acceptable performance under both groups of criteria.

Each performance criterion for all twenty-eight decision rule sets exhibited the following characteristics:

- The actual system effectivity was low due to both failure effects and idle effects. There was no significant difference between the actual system effectivity values for decision rule sets. The difference was less than 5%. High effectivity for the machine center cell usually resulted in high actual system effectivity. Also, high actual system effectivity usually inferred the low production lateness under the best decision rule sets;

- Under the traveling time criterion, there was no significant relationship with other performance criteria. This means that the traveling time criterion was independent and did not affect the other performance criteria;

- If the AS/RS cart fetched more parts, the model produced more parts (high production output). Also, the achievement rate was high under this condition. The actual production output demonstrated strong relationships with throughput time and average waiting time per part. Therefore, high production output inferred low throughtput time low average waiting time values;

- Under the throughput time criterion, the SPT/NINQ and SPT/WINQ rule sets performed very well. The throughput time criterion was most important because the criterion included failure times, idle times and delays. Because of strong relationship with the actual production output, a decision rule set which had high production output generally had a low throughput time;
- Work-in-process inventory measures except waiting time did not have strong relationships with other performance criteria. This means that the work-in-process criterion was independent and did not affect other performance criteria. The SLACK/WINQ rule set performed very well under all the work-in-process inventory measures;
- All decision rule sets generated negative production lateness (production earliness). This means that any decision rule set could be used for the FMS under the production lateness criterion. These results would have been quite different for alternate measures of generating simulation due-dates. The VALUE/WINQ rule set performed very well under the lateness criterion. The production lateness criterion had a strong relationship with the actual system effectivity. High system effectivity generally meant low production lateness;
- Because both the idle effect and the model stabilization were obtained from the actual system effectivity, a decision rule set which had high system effectivity had generally low idle effect and an early stabilization time point.

## 2. Part selection rules

From Table 7-13, the RANDOM, FSFS and VALUE rules are the first group which had high values of the actual system effectivity and low values of the production lateness. This is because of the high fetch rate for parts with the long processing times (part family 6). The SPT, DDATE, SLACK and S/PT rules are the second group which had high values of the actual production output, low throughput time and low work-in-process inventory. This is because of the high fetch rate for parts with the short processing times (part family 4).

3. Machine center selection rules

Generally, when either the machine center cell or the turning cell generated more available spaces for fetched parts under a machine center selection rule, the performance of a decision rule set containing the machine center selection rule was good. Under all performance criteria except the traveling time and the imminent operation work content, the best decision rule sets contained either the NINQ rule or WINQ rule for machine center selection. Also, the best decision rule sets had high processing rates for parts with short processing times. This means that more available spaces were generated by high processing rate for parts with short processing times.

4. Major decision rule sets

Major decision rule sets are defined as the best decision rule sets under each performance criterion. Table 8-3 presents relative ranks of the major decision rule sets for the performance criteria. According to Table 8-3, the SLACK/WINQ and SPT/WINQ rule sets dominated other major decision rule sets. The SLACK/WINQ rule set showed strong performance under the work-in-process inventory and the achievement rate criteria. The SPT/WINQ rule set showed strong performance under the throughput time and the actual production output criteria. The SPT/WINQ rule set also showed strong performance under the average traveling time per part criterion. Both decision rule sets are major rule sets in the second group which showed high performance under the actual production output, throughput time and

Table 8-3. Relative ranks for the major decision rule set

| Major decision rule set | Relative rank for Performance criteria A | B | C | D | E | F | G | H | I | J |
|---|---|---|---|---|---|---|---|---|---|---|
| RANDOM/NINQ | 1 | 26 | 27 | 16 | 16 | 13 | 16 | 24 | 9 | 7 |
| SLACK/RANDOM | 26 | 1 | 3 | 22 | 23 | 23 | 28 | 1 | 14 | 24 |
| S/PT/WINQ | 20 | 6 | 1 | 18 | 18 | 12 | 6 | 13 | 8 | 21 |
| SPT/NINQ | 23 | 27 | 8 | 1 | 4 | 2 | 22 | 6 | 4 | 25 |
| SLACK/WINQ | 27 | 11 | 10 | 4 | 1 | 4 | 1 | 2 | 1 | 27 |
| SPT/WINQ | 28 | 24 | 2 | 2 | 2 | 1 | 3 | 8 | 3 | 16 |
| VALUE/WINQ | 6 | 2 | 4 | 18 | 11 | 19 | 13 | 5 | 15 | 1 |

A = Actual system effectivity
B = Total travelling time
C = Average travelling time per part
D = Actual production output
E = Achievement rate
F = Average throughput time per part
G = Work remaining measure
H = Imminent operation work content
I = Average waiting time per part
J = Average production lateness

The SPT/WINQ rule set was also the best performer in terms of the total throughput time. The SLACK/WINQ rule set was the best performer on the basis of the total waiting time. The VALUE/WINQ rule set was also the best performer in terms of the total production lateness.

work-in-process inventory measures.

The SLACK/WINQ and SPT/WINQ rule sets used the WINQ rule as a machine center selection rule. This means that the WINQ rule dominated other machine center selection rules.

The results of the physical simulation constitute new information on work scheduling rules for flexible manufacturing systems. The use of these rules in practice, together with suggestions for further research, are discussed in the following chapter.

# IX. CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH

## A. Conclusion

As described in Chapter 8, the SLACK/WINQ and SPT/WINQ rule sets dominated all others. These decision rule sets came from the second group. The second group of rules had high values of actual production output, low throughput time and low work-in-process inventory. This is because of both the high fetch rate and the high processing rate for parts with the short processing times. The first group had high values of the actual system effectivity and low values of the production lateness. This is because of both the high fetch rate and the high processing rate for parts with the long processing times. Both of the dominant rule sets used the WINQ rule as the machine center selection rule.

Both the SLACK/WINQ and the SPT/WINQ decision rule sets can be highly recommended for use in actual flexible manufacturing systems. The reader should recall that every decision rule set had both high fetch rate and high processing rate for parts with the short processing times (either part family 4 or part family 7) as compared with other part families. The SPT rule demonstrated the highest rate in fetching and processing of part family 4. The SPT rule gave the highest priority to part family 4 because of the shortest processing time.

The SPT/WINQ rule set had the following operating features:

- More available spaces were generated on both the machine center cell and the turning cell. This means that the total number of fetches from the AS/RS cell was the 2nd highest value obtained. The model therefore manufactured the fetched parts quickly. The achievement rate was the 2nd highest value also;

. Parts with the short processing time were fetched and processed most frequently;

. Throughput time was the lowest value obtained under failures of major system components;.

. Work-in-process inventory was very low in the model due to parts with the short processing time being selected.

Every decision rule set had an actual system effectivity of approximately 60% under failures of major system components. There was a small difference (less than 0.5%) between effectivity values of decision rule sets. The actual sytem effectivity under each decision rule set could be indicative of a low system utilization rate. Because of minimum setup times, efficient workpart handling, simultaneous workpart processing and other features, the utilization rate of a flexible manufacturing system may be as high as 80% (2). This is substantiated by the fact that the relative system effectivity was approximately 80% in every decision rule set. The achievement rate of the model was approximately 70% in every decision rule set, while the processing rate for each part family exceeded 95%.

The traveling time for a decision rule set was highly dependent upon the distribution of parts on eight storage areas in every fetch. This means that the arrival rate of parts determined the traveling time for a decision rule set. If there were no parts available on a storage area specified by a part selection rule, other storage areas were selected in fetching a part. In other words, the total model fetch time was dependent upon the arrival rate. The total model route time was dependent upon the maximum queue length of either the machine center cell or the turning cell. If a machine center was full for a fetched part, other machine centers were selected for the fetched part.

All decision rule set generated negative production lateness (production earliness). This means that any decision rule set could be applied to the model to obtain low production lateness (high production earliness). These results would, of course, have been quite different under a different method of due-date generation.

## B. Suggestions for Further Research

The FMS is the latest development in manufacturing technology. This technological combination provides many interesting ideas for further research. Some possible areas of further research using a FMS physical model include:

- Determination of an optimal allocation method for part families on the AS/RS cell;
- Determination of an optimal number of machine centers and an optimal number of queue length for a workcenter;
- A comparison of physical model simulation versus digital and mathematical methods of simulation;
- Investigation of other scheduling rules for FMS facilities;
- Investigation of other due-date assignment methods;
- The use of other FMS configurations in applying the decision rule sets;

- A comparison of physical simulation with failure effects versus without failure effects.

In this physical simulation, the fetch rate for a part family has been an important factor by which various numerical results were obtained in performance criteria. Part family 4 had the shortest processing time while part family 6 had the longest processing time. The fetch rate for either part family 4 or part family 6 was a principal factor by which performance criteria, part selection rules and machine center selection rules were divided into two groups in this research. If the difference between two processing time values is either larger or smaller than the difference in this research, each decision rule set might will have generated different numerical results for performance criteria. Therefore, as another possible area for further research, the investigation for the effect of processing times on performance criteria is desirable in either digital simulation or physical simulation.

The major benefit of the physical simulation completed in this research is to convince decision-makers that a proposed design concept and control scheme are going to achieve their expected goals. This research has evaluated possible decision rule sets for a FMS physical model which is a closed loop system, and had recommended the best decision rule sets under six performance criteria. This research represents a substantial "first step" to improve the design and operation of an actual FMS installation.

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# XII. APPENDIX A:

## TIME SCALING FACTORS FOR DECISION RULE SETS

Th following data show the time scaling factor for each decision rule seet. The following notation was used in these tables:

- . I = a storage area;
- . J = a machine center;
- . TC = the turning cell;
- . AF = actual fetch time (min.);
- . AR = actual route time (min.);
- . W2 = actual DELAY-2 value (= ADELAY-2 in Chapter 4) (min.)
- . MF = model fetch time (min.);
- . MR = model route time (min.);
- . D1 = DELAY-1 value of the model (= MDELAY-1 in Chapter 4) (min.)
- . D2 = DELAY-2 value of the model (= MDELAY-2 in Chapter 4) (min.)
- . AJ = a time scaling factor for path (i,j) (= SF(i,j) in Chapter 4);
- . ND = normalization delay value of path (i,j) (= ND(i,j) in Chapter 4) (min.).

RANDOM/RANDOM

MINIMUM SCALING FACTOR= 12.2087

| I | J | AF | AR | W2 | MF | MR | D1 | D2 | AJ | ND |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | .1973 | .9766 | 7.0 | .0318 | .2017 | .20 | .1768 | 13.3932 | .0593 |
| 1 | 2 | .1973 | 1.1312 | 7.0 | .0318 | .2173 | .20 | .1768 | 13.3864 | .0583 |
| 1 | 3 | .1973 | 1.3876 | 7.0 | .0318 | .2275 | .20 | .1768 | 13.4861 | .0671 |
| 1 | 4 | .1973 | 1.6290 | 7.0 | .0318 | .2327 | .20 | .1768 | 13.7631 | .0817 |
| 1 | 5 | .1973 | 1.9183 | 7.0 | .0318 | .2427 | .20 | .1768 | 13.9875 | .0955 |
| 1 | 6 | .1973 | 2.1041 | 7.0 | .0318 | .2581 | .20 | .1768 | 13.9514 | .0852 |
| 2 | 1 | .3103 | .9766 | 7.0 | .0500 | .2017 | .20 | .1768 | 13.1852 | .0503 |
| 2 | 2 | .3103 | 1.1312 | 7.0 | .0500 | .2173 | .20 | .1768 | 13.1056 | .0474 |
| 2 | 3 | .3103 | 1.3876 | 7.0 | .0500 | .2275 | .20 | .1768 | 13.2934 | .0582 |
| 2 | 4 | .3103 | 1.6290 | 7.0 | .0500 | .2327 | .20 | .1768 | 13.5546 | .0726 |
| 2 | 5 | .3103 | 1.9183 | 7.0 | .0500 | .2427 | .20 | .1768 | 13.7858 | .0866 |
| 2 | 6 | .3103 | 2.1041 | 7.0 | .0500 | .2581 | .20 | .1768 | 13.7456 | .0863 |
| 3 | 1 | .3986 | .9766 | 7.0 | .0644 | .2017 | .20 | .1768 | 13.0287 | .0432 |
| 3 | 2 | .3986 | 1.1312 | 7.0 | .0644 | .2173 | .20 | .1768 | 12.9548 | .0403 |
| 3 | 3 | .3986 | 1.3876 | 7.0 | .0644 | .2275 | .20 | .1768 | 13.1407 | .0511 |
| 3 | 4 | .3986 | 1.6290 | 7.0 | .0644 | .2327 | .20 | .1768 | 13.3975 | .0657 |
| 3 | 5 | .3986 | 1.9183 | 7.0 | .0644 | .2427 | .20 | .1768 | 13.6261 | .0785 |
| 3 | 6 | .3986 | 2.1041 | 7.0 | .0644 | .2581 | .20 | .1768 | 13.5963 | .0782 |
| 4 | 1 | .5184 | .9766 | 7.0 | .0837 | .2017 | .20 | .1768 | 12.8299 | .0338 |
| 4 | 2 | .5184 | 1.1312 | 7.0 | .0837 | .2173 | .20 | .1768 | 12.7627 | .0308 |
| 4 | 3 | .5184 | 1.3876 | 7.0 | .0837 | .2275 | .20 | .1768 | 12.9462 | .0416 |
| 4 | 4 | .5184 | 1.6290 | 7.0 | .0837 | .2327 | .20 | .1768 | 13.1973 | .0562 |
| 4 | 5 | .5184 | 1.9183 | 7.0 | .0837 | .2427 | .20 | .1768 | 13.4224 | .0700 |
| 4 | 6 | .5184 | 2.1041 | 7.0 | .0837 | .2581 | .20 | .1768 | 13.3920 | .0697 |
| 5 | 1 | .6361 | .9766 | 7.0 | .1025 | .2017 | .20 | .1768 | 12.6471 | .0245 |
| 5 | 2 | .6361 | 1.1312 | 7.0 | .1025 | .2173 | .20 | .1768 | 12.5858 | .0216 |
| 5 | 3 | .6361 | 1.3876 | 7.0 | .1025 | .2275 | .20 | .1768 | 12.7669 | .0324 |
| 5 | 4 | .6361 | 1.6290 | 7.0 | .1025 | .2327 | .20 | .1768 | 13.0127 | .0470 |
| 5 | 5 | .6361 | 1.9183 | 7.0 | .1025 | .2427 | .20 | .1768 | 13.2346 | .0607 |
| 5 | 6 | .6361 | 2.1041 | 7.0 | .1025 | .2581 | .20 | .1768 | 13.2068 | .0605 |
| 6 | 1 | .7031 | .9766 | 7.0 | .1133 | .2017 | .20 | .1768 | 12.5465 | .0182 |
| 6 | 2 | .7031 | 1.1312 | 7.0 | .1133 | .2173 | .20 | .1768 | 12.4864 | .0163 |
| 6 | 3 | .7031 | 1.3876 | 7.0 | .1133 | .2275 | .20 | .1768 | 12.6681 | .0271 |
| 6 | 4 | .7031 | 1.6290 | 7.0 | .1133 | .2327 | .20 | .1768 | 12.9110 | .0417 |
| 6 | 5 | .7031 | 1.9183 | 7.0 | .1133 | .2427 | .20 | .1768 | 13.1310 | .0554 |
| 6 | 6 | .7031 | 2.1041 | 7.0 | .1133 | .2581 | .20 | .1768 | 13.1077 | .0552 |
| 7 | 1 | .7912 | .9766 | 7.0 | .1275 | .2017 | .20 | .1768 | 12.4188 | .0122 |
| 7 | 2 | .7912 | 1.1312 | 7.0 | .1275 | .2173 | .20 | .1768 | 12.3647 | .0093 |
| 7 | 3 | .7912 | 1.3876 | 7.0 | .1275 | .2275 | .20 | .1768 | 12.5427 | .0201 |
| 7 | 4 | .7912 | 1.6290 | 7.0 | .1275 | .2327 | .20 | .1768 | 12.7818 | .0347 |
| 7 | 5 | .7912 | 1.9183 | 7.0 | .1275 | .2427 | .20 | .1768 | 12.9983 | .0485 |
| 7 | 6 | .7912 | 2.1041 | 7.0 | .1275 | .2581 | .20 | .1768 | 12.9781 | .0482 |
| 8 | 1 | .8081 | .9766 | 7.0 | .1465 | .2017 | .20 | .1768 | 12.2561 | .0029 |
| 8 | 2 | .8081 | 1.1312 | 7.0 | .1465 | .2173 | .20 | .1768 | 12.2067 | .0000 |
| 8 | 3 | .8081 | 1.3876 | 7.0 | .1465 | .2275 | .20 | .1768 | 12.3823 | .0109 |
| 8 | 4 | .8081 | 1.6290 | 7.0 | .1465 | .2327 | .20 | .1768 | 12.6165 | .0253 |
| 8 | 5 | .8081 | 1.9183 | 7.0 | .1465 | .2427 | .20 | .1768 | 12.8308 | .0391 |
| 8 | 6 | .8081 | 2.1041 | 7.0 | .1465 | .2581 | .20 | .1768 | 12.8144 | .0389 |
| 1 | TC | .1973 | .5600 | 7.0 | .0318 | .1229 | .20 | .1768 | 14.5851 | .1039 |
| 2 | TC | .3103 | .5600 | 7.0 | .0500 | .1229 | .20 | .1768 | 14.3174 | .0950 |
| 3 | TC | .3986 | .5600 | 7.0 | .0644 | .1229 | .20 | .1768 | 14.1102 | .0879 |
| 4 | TC | .5184 | .5600 | 7.0 | .0837 | .1229 | .20 | .1768 | 13.8488 | .0784 |
| 5 | TC | .6361 | .5600 | 7.0 | .1025 | .1229 | .20 | .1768 | 13.6102 | .0652 |
| 6 | TC | .7031 | .5600 | 7.0 | .1133 | .1229 | .20 | .1768 | 13.4787 | .0639 |
| 7 | TC | .7912 | .5600 | 7.0 | .1275 | .1229 | .20 | .1768 | 13.3150 | .0569 |

RANDOM/FMFS

MINIMUM SCALING FACTOR= 12.2913

| I | J | AF | AR | W2 | MF | MR | D1 | D2 | AJ | ND |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | .1973 | .9766 | 7.0 | .0318 | .2017 | .20 | .1717 | 13.5661 | .0598 |
| 1 | 2 | .1973 | 1.1312 | 7.0 | .0318 | .2173 | .20 | .1717 | 13.4157 | .0567 |
| 1 | 3 | .1973 | 1.3876 | 7.0 | .0318 | .2275 | .20 | .1717 | 13.6052 | .0674 |
| 1 | 4 | .1973 | 1.6290 | 7.0 | .0318 | .2327 | .20 | .1717 | 13.8734 | .0818 |
| 1 | 5 | .1973 | 1.9183 | 7.0 | .0318 | .2427 | .20 | .1717 | 14.1060 | .0855 |
| 1 | 6 | .1973 | 2.1041 | 7.0 | .0318 | .2581 | .20 | .1717 | 14.0588 | .0851 |
| 2 | 1 | .3103 | .9766 | 7.0 | .0500 | .2017 | .20 | .1717 | 13.2930 | .0508 |
| 2 | 2 | .3103 | 1.1312 | 7.0 | .0500 | .2173 | .20 | .1717 | 13.2104 | .0477 |
| 2 | 3 | .3103 | 1.3876 | 7.0 | .0500 | .2275 | .20 | .1717 | 13.3878 | .0584 |
| 2 | 4 | .3103 | 1.6290 | 7.0 | .0500 | .2327 | .20 | .1717 | 13.6602 | .0728 |
| 2 | 5 | .3103 | 1.9183 | 7.0 | .0500 | .2427 | .20 | .1717 | 13.8916 | .0865 |
| 2 | 6 | .3103 | 2.1041 | 7.0 | .0500 | .2581 | .20 | .1717 | 13.8487 | .0861 |
| 3 | 1 | .3886 | .9766 | 7.0 | .0644 | .2017 | .20 | .1717 | 13.1329 | .0436 |
| 3 | 2 | .3886 | 1.1312 | 7.0 | .0644 | .2173 | .20 | .1717 | 13.0560 | .0406 |
| 3 | 3 | .3886 | 1.3876 | 7.0 | .0644 | .2275 | .20 | .1717 | 13.2417 | .0513 |
| 3 | 4 | .3886 | 1.6290 | 7.0 | .0644 | .2327 | .20 | .1717 | 13.4997 | .0657 |
| 3 | 5 | .3886 | 1.9183 | 7.0 | .0644 | .2427 | .20 | .1717 | 13.7284 | .0793 |
| 3 | 6 | .3886 | 2.1041 | 7.0 | .0644 | .2581 | .20 | .1717 | 13.6801 | .0790 |
| 4 | 1 | .5184 | .9766 | 7.0 | .0837 | .2017 | .20 | .1717 | 12.9295 | .0341 |
| 4 | 2 | .5184 | 1.1312 | 7.0 | .0837 | .2173 | .20 | .1717 | 12.8595 | .0310 |
| 4 | 3 | .5184 | 1.3876 | 7.0 | .0837 | .2275 | .20 | .1717 | 13.0428 | .0417 |
| 4 | 4 | .5184 | 1.6290 | 7.0 | .0837 | .2327 | .20 | .1717 | 13.2851 | .0561 |
| 4 | 5 | .5184 | 1.9183 | 7.0 | .0837 | .2427 | .20 | .1717 | 13.5205 | .0698 |
| 4 | 6 | .5184 | 2.1041 | 7.0 | .0837 | .2581 | .20 | .1717 | 13.4877 | .0694 |
| 5 | 1 | .6361 | .9766 | 7.0 | .1025 | .2017 | .20 | .1717 | 12.7425 | .0246 |
| 5 | 2 | .6361 | 1.1312 | 7.0 | .1025 | .2173 | .20 | .1717 | 12.6786 | .0217 |
| 5 | 3 | .6361 | 1.3876 | 7.0 | .1025 | .2275 | .20 | .1717 | 12.8597 | .0324 |
| 5 | 4 | .6361 | 1.6290 | 7.0 | .1025 | .2327 | .20 | .1717 | 13.1066 | .0468 |
| 5 | 5 | .6361 | 1.9183 | 7.0 | .1025 | .2427 | .20 | .1717 | 13.3287 | .0605 |
| 5 | 6 | .6361 | 2.1041 | 7.0 | .1025 | .2581 | .20 | .1717 | 13.3008 | .0601 |
| 6 | 1 | .7031 | .9766 | 7.0 | .1133 | .2017 | .20 | .1717 | 12.6387 | .0184 |
| 6 | 2 | .7031 | 1.1312 | 7.0 | .1133 | .2173 | .20 | .1717 | 12.5790 | .0164 |
| 6 | 3 | .7031 | 1.3876 | 7.0 | .1133 | .2275 | .20 | .1717 | 12.7588 | .0271 |
| 6 | 4 | .7031 | 1.6290 | 7.0 | .1133 | .2327 | .20 | .1717 | 13.0027 | .0415 |
| 6 | 5 | .7031 | 1.9183 | 7.0 | .1133 | .2427 | .20 | .1717 | 13.2230 | .0551 |
| 6 | 6 | .7031 | 2.1041 | 7.0 | .1133 | .2581 | .20 | .1717 | 13.1976 | .0547 |
| 7 | 1 | .7812 | .9766 | 7.0 | .1275 | .2017 | .20 | .1717 | 12.5083 | .0124 |
| 7 | 2 | .7812 | 1.1312 | 7.0 | .1275 | .2173 | .20 | .1717 | 12.4527 | .0094 |
| 7 | 3 | .7812 | 1.3876 | 7.0 | .1275 | .2275 | .20 | .1717 | 12.6307 | .0200 |
| 7 | 4 | .7812 | 1.6290 | 7.0 | .1275 | .2327 | .20 | .1717 | 12.8700 | .0345 |
| 7 | 5 | .7812 | 1.9183 | 7.0 | .1275 | .2427 | .20 | .1717 | 13.0886 | .0481 |
| 7 | 6 | .7812 | 2.1041 | 7.0 | .1275 | .2581 | .20 | .1717 | 13.0665 | .0477 |
| 8 | 1 | .8081 | .9766 | 7.0 | .1465 | .2017 | .20 | .1717 | 12.3429 | .0030 |
| 8 | 2 | .8081 | 1.1312 | 7.0 | .1465 | .2173 | .20 | .1717 | 12.2913 | .0000 |
| 8 | 3 | .8081 | 1.3876 | 7.0 | .1465 | .2275 | .20 | .1717 | 12.4670 | .0106 |
| 8 | 4 | .8081 | 1.6290 | 7.0 | .1465 | .2327 | .20 | .1717 | 12.7022 | .0251 |
| 8 | 5 | .8081 | 1.9183 | 7.0 | .1465 | .2427 | .20 | .1717 | 12.9168 | .0387 |
| 8 | 6 | .8081 | 2.1041 | 7.0 | .1465 | .2581 | .20 | .1717 | 12.8886 | .0383 |
| 1 | TC | .1973 | .5600 | 7.0 | .0318 | .1229 | .20 | .1717 | 14.7365 | .1047 |
| 2 | TC | .3103 | .5600 | 7.0 | .0500 | .1229 | .20 | .1717 | 14.4515 | .0857 |
| 3 | TC | .3886 | .5600 | 7.0 | .0644 | .1229 | .20 | .1717 | 14.2389 | .0835 |
| 4 | TC | .5184 | .5600 | 7.0 | .0837 | .1229 | .20 | .1717 | 13.9709 | .0790 |
| 5 | TC | .6361 | .5600 | 7.0 | .1025 | .1229 | .20 | .1717 | 13.7265 | .0697 |
| 6 | TC | .7031 | .5600 | 7.0 | .1133 | .1229 | .20 | .1717 | 13.5928 | .0643 |
| 7 | TC | .7812 | .5600 | 7.0 | .1275 | .1229 | .20 | .1717 | 13.4242 | .0573 |

RANDOM/NINO

MINIMUM SCALING FACTOR= 12.0795

| I | J | AF | AR | W2 | MF | MR | D1 | D2 | AJ | ND |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | .1973 | .9766 | 7.0 | .0318 | .2017 | .20 | .1846 | 13.2242 | .0585 |
| 1 | 2 | .1973 | 1.1312 | 7.0 | .0318 | .2173 | .20 | .1846 | 13.1428 | .0557 |
| 1 | 3 | .1973 | 1.3876 | 7.0 | .0318 | .2275 | .20 | .1846 | 13.3328 | .0687 |
| 1 | 4 | .1973 | 1.6280 | 7.0 | .0318 | .2327 | .20 | .1846 | 13.5877 | .0815 |
| 1 | 5 | .1973 | 1.8183 | 7.0 | .0318 | .2427 | .20 | .1846 | 13.8318 | .0958 |
| 1 | 6 | .1973 | 2.1041 | 7.0 | .0318 | .2581 | .20 | .1846 | 13.7800 | .0955 |
| 2 | 1 | .3103 | .9766 | 7.0 | .0500 | .2017 | .20 | .1846 | 13.0235 | .0497 |
| 2 | 2 | .3103 | 1.1312 | 7.0 | .0500 | .2173 | .20 | .1846 | 12.9480 | .0469 |
| 2 | 3 | .3103 | 1.3876 | 7.0 | .0500 | .2275 | .20 | .1846 | 13.1388 | .0579 |
| 2 | 4 | .3103 | 1.6280 | 7.0 | .0500 | .2327 | .20 | .1846 | 13.3962 | .0727 |
| 2 | 5 | .3103 | 1.8183 | 7.0 | .0500 | .2427 | .20 | .1846 | 13.6270 | .0867 |
| 2 | 6 | .3103 | 2.1041 | 7.0 | .0500 | .2581 | .20 | .1846 | 13.5900 | .0866 |
| 3 | 1 | .3886 | .9766 | 7.0 | .0644 | .2017 | .20 | .1846 | 12.8725 | .0427 |
| 3 | 2 | .3886 | 1.1312 | 7.0 | .0644 | .2173 | .20 | .1846 | 12.8032 | .0389 |
| 3 | 3 | .3886 | 1.3876 | 7.0 | .0644 | .2275 | .20 | .1846 | 12.9892 | .0509 |
| 3 | 4 | .3886 | 1.6280 | 7.0 | .0644 | .2327 | .20 | .1846 | 13.2442 | .0657 |
| 3 | 5 | .3886 | 1.8183 | 7.0 | .0644 | .2427 | .20 | .1846 | 13.4724 | .0797 |
| 3 | 6 | .3886 | 2.1041 | 7.0 | .0644 | .2581 | .20 | .1846 | 13.4403 | .0796 |
| 4 | 1 | .5184 | .9766 | 7.0 | .0837 | .2017 | .20 | .1846 | 12.6605 | .0333 |
| 4 | 2 | .5184 | 1.1312 | 7.0 | .0837 | .2173 | .20 | .1846 | 12.6175 | .0305 |
| 4 | 3 | .5184 | 1.3876 | 7.0 | .0837 | .2275 | .20 | .1846 | 12.8010 | .0415 |
| 4 | 4 | .5184 | 1.6280 | 7.0 | .0837 | .2327 | .20 | .1846 | 13.0504 | .0563 |
| 4 | 5 | .5184 | 1.8183 | 7.0 | .0837 | .2427 | .20 | .1846 | 13.2752 | .0703 |
| 4 | 6 | .5184 | 2.1041 | 7.0 | .0837 | .2581 | .20 | .1846 | 13.2482 | .0702 |
| 5 | 1 | .6361 | .9766 | 7.0 | .1025 | .2017 | .20 | .1846 | 12.5039 | .0242 |
| 5 | 2 | .6361 | 1.1312 | 7.0 | .1025 | .2173 | .20 | .1846 | 12.4464 | .0213 |
| 5 | 3 | .6361 | 1.3876 | 7.0 | .1025 | .2275 | .20 | .1846 | 12.6276 | .0324 |
| 5 | 4 | .6361 | 1.6280 | 7.0 | .1025 | .2327 | .20 | .1846 | 12.8717 | .0472 |
| 5 | 5 | .6361 | 1.8183 | 7.0 | .1025 | .2427 | .20 | .1846 | 13.0931 | .0612 |
| 5 | 6 | .6361 | 2.1041 | 7.0 | .1025 | .2581 | .20 | .1846 | 13.0705 | .0611 |
| 6 | 1 | .7031 | .9766 | 7.0 | .1133 | .2017 | .20 | .1846 | 12.4066 | .0189 |
| 6 | 2 | .7031 | 1.1312 | 7.0 | .1133 | .2173 | .20 | .1846 | 12.3522 | .0161 |
| 6 | 3 | .7031 | 1.3876 | 7.0 | .1133 | .2275 | .20 | .1846 | 12.5318 | .0271 |
| 6 | 4 | .7031 | 1.6280 | 7.0 | .1133 | .2327 | .20 | .1846 | 12.7732 | .0419 |
| 6 | 5 | .7031 | 1.8183 | 7.0 | .1133 | .2427 | .20 | .1846 | 12.9927 | .0559 |
| 6 | 6 | .7031 | 2.1041 | 7.0 | .1133 | .2581 | .20 | .1846 | 12.9724 | .0558 |
| 7 | 1 | .7812 | .9766 | 7.0 | .1275 | .2017 | .20 | .1846 | 12.2832 | .0120 |
| 7 | 2 | .7812 | 1.1312 | 7.0 | .1275 | .2173 | .20 | .1846 | 12.2325 | .0092 |
| 7 | 3 | .7812 | 1.3876 | 7.0 | .1275 | .2275 | .20 | .1846 | 12.4104 | .0202 |
| 7 | 4 | .7812 | 1.6280 | 7.0 | .1275 | .2327 | .20 | .1846 | 12.6479 | .0350 |
| 7 | 5 | .7812 | 1.8183 | 7.0 | .1275 | .2427 | .20 | .1846 | 12.8649 | .0490 |
| 7 | 6 | .7812 | 2.1041 | 7.0 | .1275 | .2581 | .20 | .1846 | 12.8477 | .0489 |
| 8 | 1 | .9091 | .9766 | 7.0 | .1465 | .2017 | .20 | .1846 | 12.1258 | .0028 |
| 8 | 2 | .9091 | 1.1312 | 7.0 | .1465 | .2173 | .20 | .1846 | 12.0795 | .0000 |
| 8 | 3 | .9091 | 1.3876 | 7.0 | .1465 | .2275 | .20 | .1846 | 12.2550 | .0110 |
| 8 | 4 | .9091 | 1.6280 | 7.0 | .1465 | .2327 | .20 | .1846 | 12.4876 | .0258 |
| 8 | 5 | .9091 | 1.8183 | 7.0 | .1465 | .2427 | .20 | .1846 | 12.7014 | .0398 |
| 8 | 6 | .9091 | 2.1041 | 7.0 | .1465 | .2581 | .20 | .1846 | 12.6877 | .0397 |
| 1 | TC | .1973 | .5600 | 7.0 | .0318 | .1229 | .20 | .1846 | 14.3840 | .1028 |
| 2 | TC | .3103 | .5600 | 7.0 | .0500 | .1229 | .20 | .1846 | 14.1171 | .0940 |
| 3 | TC | .3886 | .5600 | 7.0 | .0644 | .1229 | .20 | .1846 | 13.9178 | .0870 |
| 4 | TC | .5184 | .5600 | 7.0 | .0837 | .1229 | .20 | .1846 | 13.6661 | .0776 |
| 5 | TC | .6361 | .5600 | 7.0 | .1025 | .1229 | .20 | .1846 | 13.4382 | .0685 |
| 6 | TC | .7031 | .5600 | 7.0 | .1133 | .1229 | .20 | .1846 | 13.3104 | .0632 |
| 7 | TC | .7812 | .5600 | 7.0 | .1275 | .1229 | .20 | .1846 | 13.1514 | .0563 |

RANDOM/WIND

MINIMUM SCALING FACTOR= 11.8826

| I | J | AF | AR | W2 | MF | MR | D1 | D2 | AJ | ND |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | .1973 | .9766 | 7.0 | .0318 | .2017 | .20 | .1970 | 12.9641 | .0573 |
| 1 | 2 | .1973 | 1.1312 | 7.0 | .0318 | .2173 | .20 | .1970 | 12.8804 | .0547 |
| 1 | 3 | .1973 | 1.3876 | 7.0 | .0318 | .2275 | .20 | .1970 | 13.0607 | .0661 |
| 1 | 4 | .1973 | 1.6290 | 7.0 | .0318 | .2327 | .20 | .1970 | 13.3428 | .0812 |
| 1 | 5 | .1973 | 1.9183 | 7.0 | .0318 | .2427 | .20 | .1970 | 13.5764 | .0957 |
| 1 | 6 | .1973 | 2.1041 | 7.0 | .0318 | .2581 | .20 | .1970 | 13.5411 | .0958 |
| 2 | 1 | .3103 | .9766 | 7.0 | .0500 | .2017 | .20 | .1970 | 12.7748 | .0488 |
| 2 | 2 | .3103 | 1.1312 | 7.0 | .0500 | .2173 | .20 | .1970 | 12.7073 | .0461 |
| 2 | 3 | .3103 | 1.3876 | 7.0 | .0500 | .2275 | .20 | .1970 | 12.8953 | .0574 |
| 2 | 4 | .3103 | 1.6290 | 7.0 | .0500 | .2327 | .20 | .1970 | 13.1518 | .0726 |
| 2 | 5 | .3103 | 1.9183 | 7.0 | .0500 | .2427 | .20 | .1970 | 13.3820 | .0870 |
| 2 | 6 | .3103 | 2.1041 | 7.0 | .0500 | .2581 | .20 | .1970 | 13.3518 | .0871 |
| 3 | 1 | .3886 | .9766 | 7.0 | .0644 | .2017 | .20 | .1970 | 12.6318 | .0418 |
| 3 | 2 | .3886 | 1.1312 | 7.0 | .0644 | .2173 | .20 | .1970 | 12.5693 | .0392 |
| 3 | 3 | .3886 | 1.3876 | 7.0 | .0644 | .2275 | .20 | .1970 | 12.7554 | .0506 |
| 3 | 4 | .3886 | 1.6290 | 7.0 | .0644 | .2327 | .20 | .1970 | 13.0076 | .0657 |
| 3 | 5 | .3886 | 1.9183 | 7.0 | .0644 | .2427 | .20 | .1970 | 13.2351 | .0801 |
| 3 | 6 | .3886 | 2.1041 | 7.0 | .0644 | .2581 | .20 | .1970 | 13.2067 | .0802 |
| 4 | 1 | .5184 | .9766 | 7.0 | .0837 | .2017 | .20 | .1970 | 12.4501 | .0325 |
| 4 | 2 | .5184 | 1.1312 | 7.0 | .0837 | .2173 | .20 | .1970 | 12.3934 | .0300 |
| 4 | 3 | .5184 | 1.3876 | 7.0 | .0837 | .2275 | .20 | .1970 | 12.5769 | .0413 |
| 4 | 4 | .5184 | 1.6290 | 7.0 | .0837 | .2327 | .20 | .1970 | 12.8236 | .0564 |
| 4 | 5 | .5184 | 1.9183 | 7.0 | .0837 | .2427 | .20 | .1970 | 13.0476 | .0709 |
| 4 | 6 | .5184 | 2.1041 | 7.0 | .0837 | .2581 | .20 | .1970 | 13.0258 | .0710 |
| 5 | 1 | .6361 | .9766 | 7.0 | .1025 | .2017 | .20 | .1970 | 12.2828 | .0236 |
| 5 | 2 | .6361 | 1.1312 | 7.0 | .1025 | .2173 | .20 | .1970 | 12.2311 | .0210 |
| 5 | 3 | .6361 | 1.3876 | 7.0 | .1025 | .2275 | .20 | .1970 | 12.4122 | .0324 |
| 5 | 4 | .6361 | 1.6290 | 7.0 | .1025 | .2327 | .20 | .1970 | 12.6537 | .0475 |
| 5 | 5 | .6361 | 1.9183 | 7.0 | .1025 | .2427 | .20 | .1970 | 12.8744 | .0619 |
| 5 | 6 | .6361 | 2.1041 | 7.0 | .1025 | .2581 | .20 | .1970 | 12.8566 | .0621 |
| 6 | 1 | .7031 | .9766 | 7.0 | .1133 | .2017 | .20 | .1970 | 12.1805 | .0184 |
| 6 | 2 | .7031 | 1.1312 | 7.0 | .1133 | .2173 | .20 | .1970 | 12.1416 | .0158 |
| 6 | 3 | .7031 | 1.3876 | 7.0 | .1133 | .2275 | .20 | .1970 | 12.3213 | .0272 |
| 6 | 4 | .7031 | 1.6290 | 7.0 | .1133 | .2327 | .20 | .1970 | 12.5600 | .0423 |
| 6 | 5 | .7031 | 1.9183 | 7.0 | .1133 | .2427 | .20 | .1970 | 12.7787 | .0567 |
| 6 | 6 | .7031 | 2.1041 | 7.0 | .1133 | .2581 | .20 | .1970 | 12.7831 | .0568 |
| 7 | 1 | .7812 | .9766 | 7.0 | .1275 | .2017 | .20 | .1970 | 12.0735 | .0116 |
| 7 | 2 | .7812 | 1.1312 | 7.0 | .1275 | .2173 | .20 | .1970 | 12.0280 | .0090 |
| 7 | 3 | .7812 | 1.3876 | 7.0 | .1275 | .2275 | .20 | .1970 | 12.2058 | .0204 |
| 7 | 4 | .7812 | 1.6290 | 7.0 | .1275 | .2327 | .20 | .1970 | 12.4408 | .0355 |
| 7 | 5 | .7812 | 1.9183 | 7.0 | .1275 | .2427 | .20 | .1970 | 12.6570 | .0500 |
| 7 | 6 | .7812 | 2.1041 | 7.0 | .1275 | .2581 | .20 | .1970 | 12.6441 | .0501 |
| 8 | 1 | .8881 | .9766 | 7.0 | .1465 | .2017 | .20 | .1970 | 11.9238 | .0025 |
| 8 | 2 | .8881 | 1.1312 | 7.0 | .1465 | .2173 | .20 | .1970 | 11.8826 | .0000 |
| 8 | 3 | .8881 | 1.3876 | 7.0 | .1465 | .2275 | .20 | .1970 | 12.0579 | .0113 |
| 8 | 4 | .8881 | 1.6290 | 7.0 | .1465 | .2327 | .20 | .1970 | 12.2881 | .0264 |
| 8 | 5 | .8881 | 1.9183 | 7.0 | .1465 | .2427 | .20 | .1970 | 12.5011 | .0409 |
| 8 | 6 | .8881 | 2.1041 | 7.0 | .1465 | .2581 | .20 | .1970 | 12.4815 | .0410 |
| 1 | TC | .1973 | .5600 | 7.0 | .0318 | .1228 | .20 | .1970 | 14.0607 | .1011 |
| 2 | TC | .3103 | .5600 | 7.0 | .0500 | .1228 | .20 | .1970 | 13.8099 | .0924 |
| 3 | TC | .3886 | .5600 | 7.0 | .0644 | .1229 | .20 | .1970 | 13.6224 | .0855 |
| 4 | TC | .5184 | .5600 | 7.0 | .0837 | .1228 | .20 | .1970 | 13.3853 | .0763 |
| 5 | TC | .6361 | .5600 | 7.0 | .1025 | .1228 | .20 | .1970 | 13.1685 | .0673 |
| 6 | TC | .7031 | .5600 | 7.0 | .1133 | .1229 | .20 | .1970 | 13.0497 | .0621 |
| 7 | TC | .7812 | .5600 | 7.0 | .1275 | .1229 | .20 | .1970 | 12.8985 | .0554 |

FSFS/RANDOM

MINIMUM SCALING FACTOR= 12.0795

| I | J | AF | AR | W2 | MF | MR | D1 | D2 | AJ | ND |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | .1973 | .9766 | 7.0 | .0318 | .2017 | .20 | .1846 | 13.2242 | .0585 |
| 1 | 2 | .1973 | 1.1312 | 7.0 | .0318 | .2173 | .20 | .1846 | 13.1420 | .0557 |
| 1 | 3 | .1973 | 1.3876 | 7.0 | .0318 | .2275 | .20 | .1846 | 13.3326 | .0667 |
| 1 | 4 | .1973 | 1.6280 | 7.0 | .0318 | .2327 | .20 | .1846 | 13.5677 | .0815 |
| 1 | 5 | .1973 | 1.8183 | 7.0 | .0318 | .2427 | .20 | .1846 | 13.6318 | .0956 |
| 1 | 6 | .1973 | 2.1041 | 7.0 | .0318 | .2581 | .20 | .1846 | 13.7866 | .0855 |
| 2 | 1 | .3103 | .9766 | 7.0 | .0500 | .2017 | .20 | .1846 | 13.0235 | .0497 |
| 2 | 2 | .3103 | 1.1312 | 7.0 | .0500 | .2173 | .20 | .1846 | 12.9486 | .0469 |
| 2 | 3 | .3103 | 1.3876 | 7.0 | .0500 | .2275 | .20 | .1846 | 13.1388 | .0579 |
| 2 | 4 | .3103 | 1.6280 | 7.0 | .0500 | .2327 | .20 | .1846 | 13.3862 | .0727 |
| 2 | 5 | .3103 | 1.8183 | 7.0 | .0500 | .2427 | .20 | .1846 | 13.6270 | .0867 |
| 2 | 6 | .3103 | 2.1041 | 7.0 | .0500 | .2581 | .20 | .1846 | 13.5808 | .0866 |
| 3 | 1 | .3886 | .9766 | 7.0 | .0644 | .2017 | .20 | .1846 | 12.8725 | .0427 |
| 3 | 2 | .3886 | 1.1312 | 7.0 | .0644 | .2173 | .20 | .1846 | 12.8032 | .0389 |
| 3 | 3 | .3886 | 1.3876 | 7.0 | .0644 | .2275 | .20 | .1846 | 12.9892 | .0509 |
| 3 | 4 | .3886 | 1.6280 | 7.0 | .0644 | .2327 | .20 | .1846 | 13.2442 | .0657 |
| 3 | 5 | .3886 | 1.8183 | 7.0 | .0644 | .2427 | .20 | .1846 | 13.4724 | .0797 |
| 3 | 6 | .3886 | 2.1041 | 7.0 | .0644 | .2581 | .20 | .1846 | 13.4403 | .0796 |
| 4 | 1 | .5194 | .9766 | 7.0 | .0837 | .2017 | .20 | .1846 | 12.6805 | .0333 |
| 4 | 2 | .5194 | 1.1312 | 7.0 | .0837 | .2173 | .20 | .1846 | 12.6175 | .0305 |
| 4 | 3 | .5194 | 1.3876 | 7.0 | .0837 | .2275 | .20 | .1846 | 12.8010 | .0415 |
| 4 | 4 | .5194 | 1.6280 | 7.0 | .0837 | .2327 | .20 | .1846 | 13.0504 | .0563 |
| 4 | 5 | .5194 | 1.8183 | 7.0 | .0837 | .2427 | .20 | .1846 | 13.2752 | .0703 |
| 4 | 6 | .5194 | 2.1041 | 7.0 | .0837 | .2581 | .20 | .1846 | 13.2482 | .0702 |
| 5 | 1 | .6361 | .9766 | 7.0 | .1025 | .2017 | .20 | .1846 | 12.5038 | .0242 |
| 5 | 2 | .6361 | 1.1312 | 7.0 | .1025 | .2173 | .20 | .1846 | 12.4464 | .0213 |
| 5 | 3 | .6361 | 1.3876 | 7.0 | .1025 | .2275 | .20 | .1846 | 12.6276 | .0324 |
| 5 | 4 | .6361 | 1.6280 | 7.0 | .1025 | .2327 | .20 | .1846 | 12.8717 | .0472 |
| 5 | 5 | .6361 | 1.8183 | 7.0 | .1025 | .2427 | .20 | .1846 | 13.0831 | .0612 |
| 5 | 6 | .6361 | 2.1041 | 7.0 | .1025 | .2581 | .20 | .1846 | 13.0705 | .0611 |
| 6 | 1 | .7031 | .9766 | 7.0 | .1133 | .2017 | .20 | .1846 | 12.4066 | .0189 |
| 6 | 2 | .7031 | 1.1312 | 7.0 | .1133 | .2173 | .20 | .1846 | 12.3522 | .0161 |
| 6 | 3 | .7031 | 1.3876 | 7.0 | .1133 | .2275 | .20 | .1846 | 12.5319 | .0271 |
| 6 | 4 | .7031 | 1.6280 | 7.0 | .1133 | .2327 | .20 | .1846 | 12.7732 | .0413 |
| 6 | 5 | .7031 | 1.8183 | 7.0 | .1133 | .2427 | .20 | .1846 | 12.9927 | .0559 |
| 6 | 6 | .7031 | 2.1041 | 7.0 | .1133 | .2581 | .20 | .1846 | 12.9724 | .0558 |
| 7 | 1 | .7912 | .9766 | 7.0 | .1275 | .2017 | .20 | .1846 | 12.2832 | .0120 |
| 7 | 2 | .7912 | 1.1312 | 7.0 | .1275 | .2173 | .20 | .1846 | 12.2325 | .0092 |
| 7 | 3 | .7912 | 1.3876 | 7.0 | .1275 | .2275 | .20 | .1846 | 12.4104 | .0202 |
| 7 | 4 | .7912 | 1.6280 | 7.0 | .1275 | .2327 | .20 | .1846 | 12.6478 | .0350 |
| 7 | 5 | .7912 | 1.8183 | 7.0 | .1275 | .2427 | .20 | .1846 | 12.8648 | .0490 |
| 7 | 6 | .7912 | 2.1041 | 7.0 | .1275 | .2581 | .20 | .1846 | 12.8477 | .0489 |
| 8 | 1 | .9091 | .9766 | 7.0 | .1465 | .2017 | .20 | .1846 | 12.1256 | .0028 |
| 8 | 2 | .9091 | 1.1312 | 7.0 | .1465 | .2173 | .20 | .1846 | 12.0795 | .0000 |
| 8 | 3 | .9091 | 1.3876 | 7.0 | .1465 | .2275 | .20 | .1846 | 12.2556 | .0110 |
| 8 | 4 | .9091 | 1.6280 | 7.0 | .1465 | .2327 | .20 | .1846 | 12.4878 | .0258 |
| 8 | 5 | .9091 | 1.8183 | 7.0 | .1465 | .2427 | .20 | .1846 | 12.7014 | .0398 |
| 8 | 6 | .9091 | 2.1041 | 7.0 | .1465 | .2581 | .20 | .1846 | 12.6877 | .0397 |
| 1 | TC | .1973 | .5600 | 7.0 | .0318 | .1229 | .20 | .1846 | 14.3840 | .1029 |
| 2 | TC | .3103 | .5600 | 7.0 | .0500 | .1229 | .20 | .1846 | 14.1171 | .0940 |
| 3 | TC | .3886 | .5600 | 7.0 | .0644 | .1229 | .20 | .1846 | 13.9178 | .0870 |
| 4 | TC | .5194 | .5600 | 7.0 | .0837 | .1229 | .20 | .1846 | 13.6661 | .0776 |
| 5 | TC | .6361 | .5600 | 7.0 | .1025 | .1229 | .20 | .1846 | 13.4362 | .0685 |
| 6 | TC | .7031 | .5600 | 7.0 | .1133 | .1229 | .20 | .1846 | 13.3104 | .0632 |
| 7 | TC | .7912 | .5600 | 7.0 | .1275 | .1229 | .20 | .1846 | 13.1514 | .0563 |

FSFS/FMFS

MINIMUM SCALING FACTOR= 12.1687

| I | J | AF | AR | WR | MF | MR | D1 | D2 | AJ | ND |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | .1873 | .9766 | 7.0 | .0318 | .2017 | .20 | .1796 | 13.3320 | .0590 |
| 1 | 2 | .1873 | 1.1312 | 7.0 | .0318 | .2173 | .20 | .1796 | 13.2471 | .0561 |
| 1 | 3 | .1873 | 1.3876 | 7.0 | .0318 | .2275 | .20 | .1796 | 13.4376 | .0670 |
| 1 | 4 | .1873 | 1.6290 | 7.0 | .0318 | .2327 | .20 | .1796 | 13.7033 | .0817 |
| 1 | 5 | .1873 | 1.9193 | 7.0 | .0318 | .2427 | .20 | .1796 | 13.9376 | .0955 |
| 1 | 6 | .1873 | 2.1041 | 7.0 | .0318 | .2581 | .20 | .1796 | 13.8930 | .0953 |
| 2 | 1 | .3103 | .9766 | 7.0 | .0500 | .2017 | .20 | .1796 | 13.1287 | .0501 |
| 2 | 2 | .3103 | 1.1312 | 7.0 | .0500 | .2173 | .20 | .1796 | 13.0491 | .0472 |
| 2 | 3 | .3103 | 1.3876 | 7.0 | .0500 | .2275 | .20 | .1796 | 13.2367 | .0581 |
| 2 | 4 | .3103 | 1.6290 | 7.0 | .0500 | .2327 | .20 | .1796 | 13.4873 | .0727 |
| 2 | 5 | .3103 | 1.9193 | 7.0 | .0500 | .2427 | .20 | .1796 | 13.7283 | .0866 |
| 2 | 6 | .3103 | 2.1041 | 7.0 | .0500 | .2581 | .20 | .1796 | 13.6896 | .0864 |
| 3 | 1 | .3896 | .9766 | 7.0 | .0644 | .2017 | .20 | .1796 | 12.9722 | .0430 |
| 3 | 2 | .3896 | 1.1312 | 7.0 | .0644 | .2173 | .20 | .1796 | 12.9000 | .0402 |
| 3 | 3 | .3896 | 1.3876 | 7.0 | .0644 | .2275 | .20 | .1796 | 13.0859 | .0510 |
| 3 | 4 | .3896 | 1.6290 | 7.0 | .0644 | .2327 | .20 | .1796 | 13.3421 | .0657 |
| 3 | 5 | .3896 | 1.9193 | 7.0 | .0644 | .2427 | .20 | .1796 | 13.5705 | .0796 |
| 3 | 6 | .3896 | 2.1041 | 7.0 | .0644 | .2581 | .20 | .1796 | 13.5361 | .0794 |
| 4 | 1 | .5194 | .9766 | 7.0 | .0837 | .2017 | .20 | .1796 | 12.7759 | .0336 |
| 4 | 2 | .5194 | 1.1312 | 7.0 | .0837 | .2173 | .20 | .1796 | 12.7102 | .0307 |
| 4 | 3 | .5194 | 1.3876 | 7.0 | .0837 | .2275 | .20 | .1796 | 12.8937 | .0416 |
| 4 | 4 | .5194 | 1.6290 | 7.0 | .0837 | .2327 | .20 | .1796 | 13.1442 | .0562 |
| 4 | 5 | .5194 | 1.9193 | 7.0 | .0837 | .2427 | .20 | .1796 | 13.3692 | .0701 |
| 4 | 6 | .5194 | 2.1041 | 7.0 | .0837 | .2581 | .20 | .1796 | 13.3400 | .0699 |
| 5 | 1 | .6361 | .9766 | 7.0 | .1025 | .2017 | .20 | .1796 | 12.5953 | .0244 |
| 5 | 2 | .6361 | 1.1312 | 7.0 | .1025 | .2173 | .20 | .1796 | 12.5354 | .0215 |
| 5 | 3 | .6361 | 1.3876 | 7.0 | .1025 | .2275 | .20 | .1796 | 12.7166 | .0324 |
| 5 | 4 | .6361 | 1.6290 | 7.0 | .1025 | .2327 | .20 | .1796 | 12.9618 | .0470 |
| 5 | 5 | .6361 | 1.9193 | 7.0 | .1025 | .2427 | .20 | .1796 | 13.1834 | .0609 |
| 5 | 6 | .6361 | 2.1041 | 7.0 | .1025 | .2581 | .20 | .1796 | 13.1586 | .0607 |
| 6 | 1 | .7031 | .9766 | 7.0 | .1133 | .2017 | .20 | .1796 | 12.4959 | .0191 |
| 6 | 2 | .7031 | 1.1312 | 7.0 | .1133 | .2173 | .20 | .1796 | 12.4381 | .0162 |
| 6 | 3 | .7031 | 1.3876 | 7.0 | .1133 | .2275 | .20 | .1796 | 12.6169 | .0271 |
| 6 | 4 | .7031 | 1.6290 | 7.0 | .1133 | .2327 | .20 | .1796 | 12.8612 | .0417 |
| 6 | 5 | .7031 | 1.9193 | 7.0 | .1133 | .2427 | .20 | .1796 | 13.0810 | .0556 |
| 6 | 6 | .7031 | 2.1041 | 7.0 | .1133 | .2581 | .20 | .1796 | 13.0568 | .0554 |
| 7 | 1 | .7912 | .9766 | 7.0 | .1275 | .2017 | .20 | .1796 | 12.3699 | .0121 |
| 7 | 2 | .7912 | 1.1312 | 7.0 | .1275 | .2173 | .20 | .1796 | 12.3169 | .0093 |
| 7 | 3 | .7912 | 1.3876 | 7.0 | .1275 | .2275 | .20 | .1796 | 12.4848 | .0201 |
| 7 | 4 | .7912 | 1.6290 | 7.0 | .1275 | .2327 | .20 | .1796 | 12.7334 | .0348 |
| 7 | 5 | .7912 | 1.9193 | 7.0 | .1275 | .2427 | .20 | .1796 | 12.9507 | .0487 |
| 7 | 6 | .7912 | 2.1041 | 7.0 | .1275 | .2581 | .20 | .1796 | 12.9316 | .0485 |
| 8 | 1 | .8091 | .9766 | 7.0 | .1465 | .2017 | .20 | .1796 | 12.2069 | .0028 |
| 8 | 2 | .8091 | 1.1312 | 7.0 | .1465 | .2173 | .20 | .1796 | 12.1687 | .0000 |
| 8 | 3 | .8091 | 1.3876 | 7.0 | .1465 | .2275 | .20 | .1796 | 12.3383 | .0108 |
| 8 | 4 | .8091 | 1.6290 | 7.0 | .1465 | .2327 | .20 | .1796 | 12.5699 | .0255 |
| 8 | 5 | .8091 | 1.9193 | 7.0 | .1465 | .2427 | .20 | .1796 | 12.7840 | .0394 |
| 8 | 6 | .8091 | 2.1041 | 7.0 | .1465 | .2581 | .20 | .1796 | 12.7686 | .0392 |
| 1 | TC | .1873 | .5600 | 7.0 | .0318 | .1229 | .20 | .1796 | 14.5186 | .1035 |
| 2 | TC | .3103 | .5600 | 7.0 | .0500 | .1229 | .20 | .1796 | 14.2448 | .0946 |
| 3 | TC | .3896 | .5600 | 7.0 | .0644 | .1229 | .20 | .1796 | 14.0405 | .0876 |
| 4 | TC | .5194 | .5600 | 7.0 | .0837 | .1229 | .20 | .1796 | 13.7826 | .0781 |
| 5 | TC | .6361 | .5600 | 7.0 | .1025 | .1229 | .20 | .1796 | 13.5472 | .0689 |
| 6 | TC | .7031 | .5600 | 7.0 | .1133 | .1229 | .20 | .1796 | 13.4184 | .0636 |
| 7 | TC | .7912 | .5600 | 7.0 | .1275 | .1229 | .20 | .1796 | 13.2558 | .0567 |

FSFS/NINO

MINIMUM SCALING FACTOR= 11.9818

| I | J | AF | AR | WR | MF | MR | D1 | D2 | AJ | ND |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | .1973 | .9766 | 7.0 | .0318 | .2017 | .20 | .1907 | 13.0356 | .0579 |
| 1 | 2 | .1973 | 1.1312 | 7.0 | .0318 | .2173 | .20 | .1907 | 13.0173 | .0552 |
| 1 | 3 | .1973 | 1.3876 | 7.0 | .0318 | .2275 | .20 | .1907 | 13.2075 | .0684 |
| 1 | 4 | .1973 | 1.6290 | 7.0 | .0318 | .2327 | .20 | .1907 | 13.4711 | .0814 |
| 1 | 5 | .1973 | 1.9183 | 7.0 | .0318 | .2427 | .20 | .1907 | 13.7050 | .0956 |
| 1 | 6 | .1973 | 2.1041 | 7.0 | .0318 | .2581 | .20 | .1907 | 13.6664 | .0956 |
| 2 | 1 | .3103 | .9766 | 7.0 | .0500 | .2017 | .20 | .1907 | 12.9999 | .0492 |
| 2 | 2 | .3103 | 1.1312 | 7.0 | .0500 | .2173 | .20 | .1907 | 12.9290 | .0465 |
| 2 | 3 | .3103 | 1.3876 | 7.0 | .0500 | .2275 | .20 | .1907 | 13.0189 | .0577 |
| 2 | 4 | .3103 | 1.6290 | 7.0 | .0500 | .2327 | .20 | .1907 | 13.2740 | .0726 |
| 2 | 5 | .3103 | 1.9183 | 7.0 | .0500 | .2427 | .20 | .1907 | 13.5054 | .0869 |
| 2 | 6 | .3103 | 2.1041 | 7.0 | .0500 | .2581 | .20 | .1907 | 13.4722 | .0869 |
| 3 | 1 | .3986 | .9766 | 7.0 | .0644 | .2017 | .20 | .1907 | 12.7530 | .0422 |
| 3 | 2 | .3986 | 1.1312 | 7.0 | .0644 | .2173 | .20 | .1907 | 12.6870 | .0395 |
| 3 | 3 | .3986 | 1.3876 | 7.0 | .0644 | .2275 | .20 | .1907 | 12.8731 | .0507 |
| 3 | 4 | .3986 | 1.6290 | 7.0 | .0644 | .2327 | .20 | .1907 | 13.1267 | .0657 |
| 3 | 5 | .3986 | 1.9183 | 7.0 | .0644 | .2427 | .20 | .1907 | 13.3540 | .0799 |
| 3 | 6 | .3986 | 2.1041 | 7.0 | .0644 | .2581 | .20 | .1907 | 13.3254 | .0799 |
| 4 | 1 | .5194 | .9766 | 7.0 | .0837 | .2017 | .20 | .1907 | 12.5661 | .0329 |
| 4 | 2 | .5194 | 1.1312 | 7.0 | .0837 | .2173 | .20 | .1907 | 12.5062 | .0302 |
| 4 | 3 | .5194 | 1.3876 | 7.0 | .0837 | .2275 | .20 | .1907 | 12.6698 | .0414 |
| 4 | 4 | .5194 | 1.6290 | 7.0 | .0837 | .2327 | .20 | .1907 | 12.9379 | .0564 |
| 4 | 5 | .5194 | 1.9183 | 7.0 | .0837 | .2427 | .20 | .1907 | 13.1623 | .0706 |
| 4 | 6 | .5194 | 2.1041 | 7.0 | .0837 | .2581 | .20 | .1907 | 13.1379 | .0706 |
| 5 | 1 | .6361 | .9766 | 7.0 | .1025 | .2017 | .20 | .1907 | 12.3941 | .0239 |
| 5 | 2 | .6361 | 1.1312 | 7.0 | .1025 | .2173 | .20 | .1907 | 12.3396 | .0212 |
| 5 | 3 | .6361 | 1.3876 | 7.0 | .1025 | .2275 | .20 | .1907 | 12.5207 | .0324 |
| 5 | 4 | .6361 | 1.6290 | 7.0 | .1025 | .2327 | .20 | .1907 | 12.7636 | .0473 |
| 5 | 5 | .6361 | 1.9183 | 7.0 | .1025 | .2427 | .20 | .1907 | 12.9646 | .0615 |
| 5 | 6 | .6361 | 2.1041 | 7.0 | .1025 | .2581 | .20 | .1907 | 12.9644 | .0616 |
| 6 | 1 | .7031 | .9766 | 7.0 | .1133 | .2017 | .20 | .1907 | 12.2894 | .0187 |
| 6 | 2 | .7031 | 1.1312 | 7.0 | .1133 | .2173 | .20 | .1907 | 12.2477 | .0160 |
| 6 | 3 | .7031 | 1.3876 | 7.0 | .1133 | .2275 | .20 | .1907 | 12.4274 | .0272 |
| 6 | 4 | .7031 | 1.6290 | 7.0 | .1133 | .2327 | .20 | .1907 | 12.6674 | .0421 |
| 6 | 5 | .7031 | 1.9183 | 7.0 | .1133 | .2427 | .20 | .1907 | 12.8865 | .0563 |
| 6 | 6 | .7031 | 2.1041 | 7.0 | .1133 | .2581 | .20 | .1907 | 12.8696 | .0564 |
| 7 | 1 | .7912 | .9766 | 7.0 | .1275 | .2017 | .20 | .1907 | 12.1791 | .0118 |
| 7 | 2 | .7912 | 1.1312 | 7.0 | .1275 | .2173 | .20 | .1907 | 12.1310 | .0091 |
| 7 | 3 | .7912 | 1.3876 | 7.0 | .1275 | .2275 | .20 | .1907 | 12.3069 | .0203 |
| 7 | 4 | .7912 | 1.6290 | 7.0 | .1275 | .2327 | .20 | .1907 | 12.5452 | .0353 |
| 7 | 5 | .7912 | 1.9183 | 7.0 | .1275 | .2427 | .20 | .1907 | 12.7610 | .0495 |
| 7 | 6 | .7912 | 2.1041 | 7.0 | .1275 | .2581 | .20 | .1907 | 12.7467 | .0495 |
| 8 | 1 | .8091 | .9766 | 7.0 | .1465 | .2017 | .20 | .1907 | 12.0255 | .0026 |
| 8 | 2 | .8091 | 1.1312 | 7.0 | .1465 | .2173 | .20 | .1907 | 11.9818 | .0000 |
| 8 | 3 | .8091 | 1.3876 | 7.0 | .1465 | .2275 | .20 | .1907 | 12.1573 | .0112 |
| 8 | 4 | .8091 | 1.6290 | 7.0 | .1465 | .2327 | .20 | .1907 | 12.3887 | .0261 |
| 8 | 5 | .8091 | 1.9183 | 7.0 | .1465 | .2427 | .20 | .1907 | 12.6021 | .0403 |
| 8 | 6 | .8091 | 2.1041 | 7.0 | .1465 | .2581 | .20 | .1907 | 12.5904 | .0404 |
| 1 | TC | .1973 | .5600 | 7.0 | .0318 | .1229 | .20 | .1907 | 14.2231 | .1020 |
| 2 | TC | .3103 | .5600 | 7.0 | .0500 | .1229 | .20 | .1907 | 13.9643 | .0932 |
| 3 | TC | .3986 | .5600 | 7.0 | .0644 | .1229 | .20 | .1907 | 13.7709 | .0863 |
| 4 | TC | .5194 | .5600 | 7.0 | .0837 | .1229 | .20 | .1907 | 13.5265 | .0770 |
| 5 | TC | .6361 | .5600 | 7.0 | .1025 | .1229 | .20 | .1907 | 13.3031 | .0673 |
| 6 | TC | .7031 | .5600 | 7.0 | .1133 | .1229 | .20 | .1907 | 13.1600 | .0627 |
| 7 | TC | .7912 | .5600 | 7.0 | .1275 | .1229 | .20 | .1907 | 13.0263 | .0558 |

FSFS/WING

MINIMUM SCALING FACTOR= 11.8065

| I | J | AF | AR | W2 | MF | MR | D1 | D2 | AJ | ND |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | .1973 | .9766 | 7.0 | .0318 | .2017 | .20 | .2019 | 12.8641 | .0569 |
| 1 | 2 | .1973 | 1.1312 | 7.0 | .0318 | .2173 | .20 | .2019 | 12.7933 | .0544 |
| 1 | 3 | .1973 | 1.3876 | 7.0 | .0318 | .2275 | .20 | .2019 | 12.9838 | .0659 |
| 1 | 4 | .1973 | 1.6280 | 7.0 | .0318 | .2327 | .20 | .2019 | 13.2447 | .0811 |
| 1 | 5 | .1973 | 1.9193 | 7.0 | .0318 | .2427 | .20 | .2019 | 13.4781 | .0957 |
| 1 | 6 | .1973 | 2.1041 | 7.0 | .0318 | .2581 | .20 | .2019 | 13.4452 | .0980 |
| 2 | 1 | .3103 | .9766 | 7.0 | .0500 | .2017 | .20 | .2019 | 12.6786 | .0482 |
| 2 | 2 | .3103 | 1.1312 | 7.0 | .0500 | .2173 | .20 | .2019 | 12.6143 | .0457 |
| 2 | 3 | .3103 | 1.3876 | 7.0 | .0500 | .2275 | .20 | .2019 | 12.8023 | .0573 |
| 2 | 4 | .3103 | 1.6280 | 7.0 | .0500 | .2327 | .20 | .2019 | 13.0576 | .0725 |
| 2 | 5 | .3103 | 1.9193 | 7.0 | .0500 | .2427 | .20 | .2019 | 13.2876 | .0871 |
| 2 | 6 | .3103 | 2.1041 | 7.0 | .0500 | .2581 | .20 | .2019 | 13.2587 | .0873 |
| 3 | 1 | .3886 | .9766 | 7.0 | .0644 | .2017 | .20 | .2019 | 12.5392 | .0414 |
| 3 | 2 | .3886 | 1.1312 | 7.0 | .0644 | .2173 | .20 | .2019 | 12.4792 | .0389 |
| 3 | 3 | .3886 | 1.3876 | 7.0 | .0644 | .2275 | .20 | .2019 | 12.6653 | .0504 |
| 3 | 4 | .3886 | 1.6280 | 7.0 | .0644 | .2327 | .20 | .2019 | 12.9164 | .0657 |
| 3 | 5 | .3886 | 1.9193 | 7.0 | .0644 | .2427 | .20 | .2019 | 13.1437 | .0803 |
| 3 | 6 | .3886 | 2.1041 | 7.0 | .0644 | .2581 | .20 | .2019 | 13.1184 | .0805 |
| 4 | 1 | .5184 | .9766 | 7.0 | .0837 | .2017 | .20 | .2019 | 12.3614 | .0323 |
| 4 | 2 | .5184 | 1.1312 | 7.0 | .0837 | .2173 | .20 | .2019 | 12.3070 | .0297 |
| 4 | 3 | .5184 | 1.3876 | 7.0 | .0837 | .2275 | .20 | .2019 | 12.4865 | .0413 |
| 4 | 4 | .5184 | 1.6280 | 7.0 | .0837 | .2327 | .20 | .2019 | 12.7361 | .0565 |
| 4 | 5 | .5184 | 1.9193 | 7.0 | .0837 | .2427 | .20 | .2019 | 12.9569 | .0711 |
| 4 | 6 | .5184 | 2.1041 | 7.0 | .0837 | .2581 | .20 | .2019 | 12.9400 | .0714 |
| 5 | 1 | .6361 | .9766 | 7.0 | .1025 | .2017 | .20 | .2019 | 12.1975 | .0233 |
| 5 | 2 | .6361 | 1.1312 | 7.0 | .1025 | .2173 | .20 | .2019 | 12.1481 | .0208 |
| 5 | 3 | .6361 | 1.3876 | 7.0 | .1025 | .2275 | .20 | .2019 | 12.3281 | .0323 |
| 5 | 4 | .6361 | 1.6280 | 7.0 | .1025 | .2327 | .20 | .2019 | 12.5686 | .0476 |
| 5 | 5 | .6361 | 1.9193 | 7.0 | .1025 | .2427 | .20 | .2019 | 12.7889 | .0622 |
| 5 | 6 | .6361 | 2.1041 | 7.0 | .1025 | .2581 | .20 | .2019 | 12.7740 | .0624 |
| 6 | 1 | .7031 | .9766 | 7.0 | .1133 | .2017 | .20 | .2019 | 12.1072 | .0182 |
| 6 | 2 | .7031 | 1.1312 | 7.0 | .1133 | .2173 | .20 | .2019 | 12.0604 | .0157 |
| 6 | 3 | .7031 | 1.3876 | 7.0 | .1133 | .2275 | .20 | .2019 | 12.2400 | .0272 |
| 6 | 4 | .7031 | 1.6280 | 7.0 | .1133 | .2327 | .20 | .2019 | 12.4777 | .0425 |
| 6 | 5 | .7031 | 1.9193 | 7.0 | .1133 | .2427 | .20 | .2019 | 12.6861 | .0571 |
| 6 | 6 | .7031 | 2.1041 | 7.0 | .1133 | .2581 | .20 | .2019 | 12.6822 | .0573 |
| 7 | 1 | .7912 | .9766 | 7.0 | .1275 | .2017 | .20 | .2019 | 11.9826 | .0115 |
| 7 | 2 | .7912 | 1.1312 | 7.0 | .1275 | .2173 | .20 | .2019 | 11.9491 | .0080 |
| 7 | 3 | .7912 | 1.3876 | 7.0 | .1275 | .2275 | .20 | .2019 | 12.1288 | .0205 |
| 7 | 4 | .7912 | 1.6280 | 7.0 | .1275 | .2327 | .20 | .2019 | 12.3866 | .0357 |
| 7 | 5 | .7912 | 1.9193 | 7.0 | .1275 | .2427 | .20 | .2019 | 12.5767 | .0503 |
| 7 | 6 | .7912 | 2.1041 | 7.0 | .1275 | .2581 | .20 | .2019 | 12.5654 | .0506 |
| 8 | 1 | .8081 | .9766 | 7.0 | .1465 | .2017 | .20 | .2019 | 11.8460 | .0025 |
| 8 | 2 | .8081 | 1.1312 | 7.0 | .1465 | .2173 | .20 | .2019 | 11.8065 | .0000 |
| 8 | 3 | .8081 | 1.3876 | 7.0 | .1465 | .2275 | .20 | .2019 | 11.9818 | .0115 |
| 8 | 4 | .8081 | 1.6280 | 7.0 | .1465 | .2327 | .20 | .2019 | 12.2111 | .0267 |
| 8 | 5 | .8081 | 1.9193 | 7.0 | .1465 | .2427 | .20 | .2019 | 12.4237 | .0413 |
| 8 | 6 | .8081 | 2.1041 | 7.0 | .1465 | .2561 | .20 | .2019 | 12.4156 | .0416 |
| 1 | TC | .1973 | .5600 | 7.0 | .0318 | .1228 | .20 | .2019 | 13.8369 | .1004 |
| 2 | TC | .3103 | .5600 | 7.0 | .0500 | .1228 | .20 | .2019 | 13.6922 | .0918 |
| 3 | TC | .3886 | .5600 | 7.0 | .0644 | .1228 | .20 | .2019 | 13.5091 | .0849 |
| 4 | TC | .5184 | .5600 | 7.0 | .0837 | .1228 | .20 | .2019 | 13.2775 | .0758 |
| 5 | TC | .6361 | .5600 | 7.0 | .1025 | .1228 | .20 | .2019 | 13.0656 | .0669 |
| 6 | TC | .7031 | .5600 | 7.0 | .1133 | .1228 | .20 | .2019 | 12.9495 | .0617 |
| 7 | TC | .7912 | .5600 | 7.0 | .1275 | .1228 | .20 | .2019 | 12.8026 | .0550 |

SPT/RANDOM

MINIMUM SCALING FACTOR= 11.8966

| I | J | AF | AR | WR | MF | MR | D1 | D2 | AJ | ND |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | .1973 | .9766 | 7.0 | .0318 | .2017 | .20 | .1961 | 12.9928 | .0574 |
| 1 | 2 | .1973 | 1.1312 | 7.0 | .0318 | .2173 | .20 | .1961 | 12.9904 | .0548 |
| 1 | 3 | .1973 | 1.3876 | 7.0 | .0318 | .2275 | .20 | .1961 | 13.0997 | .0588 |
| 1 | 4 | .1973 | 1.6290 | 7.0 | .0318 | .2327 | .20 | .1961 | 13.3610 | .0813 |
| 1 | 5 | .1973 | 1.9193 | 7.0 | .0318 | .2427 | .20 | .1961 | 13.5946 | .0857 |
| 1 | 6 | .1973 | 2.1041 | 7.0 | .0318 | .2581 | .20 | .1961 | 13.5588 | .0858 |
| 2 | 1 | .3103 | .9766 | 7.0 | .0500 | .2017 | .20 | .1961 | 12.7983 | .0487 |
| 2 | 2 | .3103 | 1.1312 | 7.0 | .0500 | .2173 | .20 | .1961 | 12.7246 | .0461 |
| 2 | 3 | .3103 | 1.3876 | 7.0 | .0500 | .2275 | .20 | .1961 | 12.9125 | .0575 |
| 2 | 4 | .3103 | 1.6290 | 7.0 | .0500 | .2327 | .20 | .1961 | 13.1692 | .0726 |
| 2 | 5 | .3103 | 1.9193 | 7.0 | .0500 | .2427 | .20 | .1961 | 13.3895 | .0870 |
| 2 | 6 | .3103 | 2.1041 | 7.0 | .0500 | .2581 | .20 | .1961 | 13.3689 | .0871 |
| 3 | 1 | .3986 | .9766 | 7.0 | .0644 | .2017 | .20 | .1961 | 12.6490 | .0418 |
| 3 | 2 | .3986 | 1.1312 | 7.0 | .0644 | .2173 | .20 | .1961 | 12.5860 | .0392 |
| 3 | 3 | .3986 | 1.3876 | 7.0 | .0644 | .2275 | .20 | .1961 | 12.7720 | .0506 |
| 3 | 4 | .3986 | 1.6290 | 7.0 | .0644 | .2327 | .20 | .1961 | 13.0245 | .0657 |
| 3 | 5 | .3986 | 1.9193 | 7.0 | .0644 | .2427 | .20 | .1961 | 13.2521 | .0801 |
| 3 | 6 | .3986 | 2.1041 | 7.0 | .0644 | .2581 | .20 | .1961 | 13.2252 | .0802 |
| 4 | 1 | .5194 | .9766 | 7.0 | .0837 | .2017 | .20 | .1961 | 12.4866 | .0326 |
| 4 | 2 | .5194 | 1.1312 | 7.0 | .0837 | .2173 | .20 | .1961 | 12.4094 | .0300 |
| 4 | 3 | .5194 | 1.3876 | 7.0 | .0837 | .2275 | .20 | .1961 | 12.5929 | .0414 |
| 4 | 4 | .5194 | 1.6290 | 7.0 | .0837 | .2327 | .20 | .1961 | 12.8398 | .0564 |
| 4 | 5 | .5194 | 1.9193 | 7.0 | .0837 | .2427 | .20 | .1961 | 13.0639 | .0708 |
| 4 | 6 | .5194 | 2.1041 | 7.0 | .0837 | .2581 | .20 | .1961 | 13.0417 | .0710 |
| 5 | 1 | .6361 | .9766 | 7.0 | .1025 | .2017 | .20 | .1961 | 12.2085 | .0236 |
| 5 | 2 | .6361 | 1.1312 | 7.0 | .1025 | .2173 | .20 | .1961 | 12.2469 | .0210 |
| 5 | 3 | .6361 | 1.3876 | 7.0 | .1025 | .2275 | .20 | .1961 | 12.2276 | .0324 |
| 5 | 4 | .6361 | 1.6290 | 7.0 | .1025 | .2327 | .20 | .1961 | 12.6693 | .0475 |
| 5 | 5 | .6361 | 1.9193 | 7.0 | .1025 | .2427 | .20 | .1961 | 12.8900 | .0619 |
| 5 | 6 | .6361 | 2.1041 | 7.0 | .1025 | .2581 | .20 | .1961 | 12.8719 | .0620 |
| 6 | 1 | .7031 | .9766 | 7.0 | .1133 | .2017 | .20 | .1961 | 12.2060 | .0184 |
| 6 | 2 | .7031 | 1.1312 | 7.0 | .1133 | .2173 | .20 | .1961 | 12.1567 | .0158 |
| 6 | 3 | .7031 | 1.3876 | 7.0 | .1133 | .2275 | .20 | .1961 | 12.3364 | .0272 |
| 6 | 4 | .7031 | 1.6290 | 7.0 | .1133 | .2327 | .20 | .1961 | 12.5752 | .0423 |
| 6 | 5 | .7031 | 1.9193 | 7.0 | .1133 | .2427 | .20 | .1961 | 12.7940 | .0567 |
| 6 | 6 | .7031 | 2.1041 | 7.0 | .1133 | .2581 | .20 | .1961 | 12.7781 | .0568 |
| 7 | 1 | .7812 | .9766 | 7.0 | .1275 | .2017 | .20 | .1961 | 12.0685 | .0117 |
| 7 | 2 | .7812 | 1.1312 | 7.0 | .1275 | .2173 | .20 | .1961 | 12.0426 | .0090 |
| 7 | 3 | .7812 | 1.3876 | 7.0 | .1275 | .2275 | .20 | .1961 | 12.2204 | .0204 |
| 7 | 4 | .7812 | 1.6290 | 7.0 | .1275 | .2327 | .20 | .1961 | 12.4556 | .0355 |
| 7 | 5 | .7812 | 1.9193 | 7.0 | .1275 | .2427 | .20 | .1961 | 12.6718 | .0499 |
| 7 | 6 | .7812 | 2.1041 | 7.0 | .1275 | .2581 | .20 | .1961 | 12.6586 | .0500 |
| 8 | 1 | .8891 | .9766 | 7.0 | .1465 | .2017 | .20 | .1961 | 11.9383 | .0026 |
| 8 | 2 | .8891 | 1.1312 | 7.0 | .1465 | .2173 | .20 | .1961 | 11.8966 | .0000 |
| 8 | 3 | .8891 | 1.3876 | 7.0 | .1465 | .2275 | .20 | .1961 | 12.0720 | .0113 |
| 8 | 4 | .8891 | 1.6290 | 7.0 | .1465 | .2327 | .20 | .1961 | 12.3024 | .0264 |
| 8 | 5 | .8891 | 1.9193 | 7.0 | .1465 | .2427 | .20 | .1961 | 12.5154 | .0408 |
| 8 | 6 | .8891 | 2.1041 | 7.0 | .1465 | .2581 | .20 | .1961 | 12.5055 | .0409 |
| 1 | TC | .1973 | .5600 | 7.0 | .0318 | .1229 | .20 | .1961 | 14.0836 | .1012 |
| 2 | TC | .3103 | .5600 | 7.0 | .0500 | .1229 | .20 | .1961 | 13.8318 | .0925 |
| 3 | TC | .3986 | .5600 | 7.0 | .0644 | .1229 | .20 | .1961 | 13.6434 | .0856 |
| 4 | TC | .5194 | .5600 | 7.0 | .0837 | .1229 | .20 | .1961 | 13.4053 | .0764 |
| 5 | TC | .6361 | .5600 | 7.0 | .1025 | .1229 | .20 | .1961 | 13.1876 | .0674 |
| 6 | TC | .7031 | .5600 | 7.0 | .1133 | .1229 | .20 | .1961 | 13.0683 | .0622 |
| 7 | TC | .7912 | .5600 | 7.0 | .1275 | .1229 | .20 | .1961 | 12.9175 | .0554 |

SPT/FMFS

MINIMUM SCALING FACTOR= 12.1248

| I | J | AF | AR | WE | MF | MR | D1 | D2 | AJ | NO |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | .1973 | .8766 | 7.0 | .0318 | .2017 | .20 | .1818 | 13.2844 | .0588 |
| 1 | 2 | .1973 | 1.1312 | 7.0 | .0318 | .2173 | .20 | .1818 | 13.2609 | .0559 |
| 1 | 3 | .1973 | 1.3876 | 7.0 | .0318 | .2275 | .20 | .1818 | 13.3908 | .0669 |
| 1 | 4 | .1973 | 1.6280 | 7.0 | .0318 | .2327 | .20 | .1818 | 13.6566 | .0816 |
| 1 | 5 | .1973 | 1.8193 | 7.0 | .0318 | .2427 | .20 | .1818 | 13.2928 | .0955 |
| 1 | 6 | .1973 | 2.1041 | 7.0 | .0318 | .2581 | .20 | .1818 | 13.8475 | .0854 |
| 2 | 1 | .3103 | .8766 | 7.0 | .0500 | .2017 | .20 | .1818 | 13.0811 | .0499 |
| 2 | 2 | .3103 | 1.1312 | 7.0 | .0500 | .2173 | .20 | .1818 | 13.0049 | .0471 |
| 2 | 3 | .3103 | 1.3876 | 7.0 | .0500 | .2275 | .20 | .1818 | 13.1926 | .0580 |
| 2 | 4 | .3103 | 1.6280 | 7.0 | .0500 | .2327 | .20 | .1818 | 13.4586 | .0727 |
| 2 | 5 | .3103 | 1.8193 | 7.0 | .0500 | .2427 | .20 | .1818 | 13.6836 | .0867 |
| 2 | 6 | .3103 | 2.1041 | 7.0 | .0500 | .2581 | .20 | .1818 | 13.6460 | .0865 |
| 3 | 1 | .3886 | .8766 | 7.0 | .0644 | .2017 | .20 | .1818 | 12.9282 | .0429 |
| 3 | 2 | .3886 | 1.1312 | 7.0 | .0644 | .2173 | .20 | .1818 | 12.8572 | .0400 |
| 3 | 3 | .3886 | 1.3876 | 7.0 | .0644 | .2275 | .20 | .1818 | 13.0431 | .0510 |
| 3 | 4 | .3886 | 1.6280 | 7.0 | .0644 | .2327 | .20 | .1818 | 13.2988 | .0657 |
| 3 | 5 | .3886 | 1.8193 | 7.0 | .0644 | .2427 | .20 | .1818 | 13.5272 | .0798 |
| 3 | 6 | .3886 | 2.1041 | 7.0 | .0644 | .2581 | .20 | .1818 | 13.4938 | .0795 |
| 4 | 1 | .5184 | .8766 | 7.0 | .0837 | .2017 | .20 | .1818 | 12.7338 | .0335 |
| 4 | 2 | .5184 | 1.1312 | 7.0 | .0837 | .2173 | .20 | .1818 | 12.6693 | .0306 |
| 4 | 3 | .5134 | 1.3876 | 7.0 | .0837 | .2275 | .20 | .1818 | 12.8528 | .0416 |
| 4 | 4 | .5184 | 1.6280 | 7.0 | .0837 | .2327 | .20 | .1818 | 13.1028 | .0563 |
| 4 | 5 | .5184 | 1.8193 | 7.0 | .0837 | .2427 | .20 | .1818 | 13.3277 | .0702 |
| 4 | 6 | .5184 | 2.1041 | 7.0 | .0837 | .2581 | .20 | .1818 | 13.2884 | .0701 |
| 5 | 1 | .6361 | .8766 | 7.0 | .1025 | .2017 | .20 | .1818 | 12.5548 | .0243 |
| 5 | 2 | .6361 | 1.1312 | 7.0 | .1025 | .2173 | .20 | .1818 | 12.4961 | .0214 |
| 5 | 3 | .6361 | 1.3876 | 7.0 | .1025 | .2275 | .20 | .1818 | 12.6772 | .0324 |
| 5 | 4 | .6361 | 1.6280 | 7.0 | .1025 | .2327 | .20 | .1818 | 12.9220 | .0471 |
| 5 | 5 | .6361 | 1.8193 | 7.0 | .1025 | .2427 | .20 | .1818 | 13.1436 | .0610 |
| 5 | 6 | .6361 | 2.1041 | 7.0 | .1025 | .2581 | .20 | .1818 | 13.1186 | .0609 |
| 6 | 1 | .7031 | .8766 | 7.0 | .1133 | .2017 | .20 | .1818 | 12.4565 | .0180 |
| 6 | 2 | .7031 | 1.1312 | 7.0 | .1133 | .2173 | .20 | .1818 | 12.4007 | .0162 |
| 6 | 3 | .7031 | 1.3876 | 7.0 | .1133 | .2275 | .20 | .1818 | 12.5805 | .0271 |
| 6 | 4 | .7031 | 1.6280 | 7.0 | .1133 | .2327 | .20 | .1818 | 12.8223 | .0418 |
| 6 | 5 | .7031 | 1.8193 | 7.0 | .1133 | .2427 | .20 | .1818 | 13.0420 | .0558 |
| 6 | 6 | .7031 | 2.1041 | 7.0 | .1133 | .2581 | .20 | .1818 | 13.0207 | .0556 |
| 7 | 1 | .7812 | .8766 | 7.0 | .1275 | .2017 | .20 | .1818 | 12.3316 | .0121 |
| 7 | 2 | .7812 | 1.1312 | 7.0 | .1275 | .2173 | .20 | .1818 | 12.2786 | .0092 |
| 7 | 3 | .7812 | 1.3876 | 7.0 | .1275 | .2275 | .20 | .1818 | 12.4576 | .0202 |
| 7 | 4 | .7812 | 1.6280 | 7.0 | .1275 | .2327 | .20 | .1818 | 12.6956 | .0349 |
| 7 | 5 | .7812 | 1.8193 | 7.0 | .1275 | .2427 | .20 | .1818 | 12.9128 | .0488 |
| 7 | 6 | .7812 | 2.1041 | 7.0 | .1275 | .2581 | .20 | .1818 | 12.8845 | .0487 |
| 8 | 1 | .8081 | .8766 | 7.0 | .1465 | .2017 | .20 | .1818 | 12.1721 | .0028 |
| 8 | 2 | .8081 | 1.1312 | 7.0 | .1465 | .2173 | .20 | .1818 | 12.1248 | .0000 |
| 8 | 3 | .8081 | 1.3876 | 7.0 | .1465 | .2275 | .20 | .1818 | 12.3004 | .0109 |
| 8 | 4 | .8081 | 1.6280 | 7.0 | .1465 | .2327 | .20 | .1818 | 12.5336 | .0256 |
| 8 | 5 | .8081 | 1.8193 | 7.0 | .1465 | .2427 | .20 | .1818 | 12.7476 | .0396 |
| 8 | 6 | .8081 | 2.1041 | 7.0 | .1465 | .2581 | .20 | .1818 | 12.7329 | .0394 |
| 1 | TC | .1973 | .5600 | 7.0 | .0318 | .1229 | .20 | .1818 | 14.4590 | .1032 |
| 2 | TC | .3103 | .5600 | 7.0 | .0500 | .1229 | .20 | .1818 | 14.1883 | .0944 |
| 3 | TC | .3886 | .5600 | 7.0 | .0644 | .1229 | .20 | .1818 | 13.9862 | .0873 |
| 4 | TC | .5184 | .5600 | 7.0 | .0837 | .1229 | .20 | .1818 | 13.7311 | .0779 |
| 5 | TC | .6361 | .5600 | 7.0 | .1025 | .1229 | .20 | .1818 | 13.4981 | .0687 |
| 6 | TC | .7031 | .5600 | 7.0 | .1133 | .1229 | .20 | .1818 | 13.3707 | .0635 |
| 7 | TC | .7812 | .5600 | 7.0 | .1275 | .1229 | .20 | .1818 | 13.2097 | .0565 |

SPT/NINQ

MINIMUM SCALING FACTOR= 11.8468

| I | J | AF | AR | W2 | MF | MR | D1 | D2 | AJ | NO |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | .1873 | .9766 | 7.0 | .0318 | .2017 | .20 | .1993 | 12.9170 | .0571 |
| 1 | 2 | .1873 | 1.1312 | 7.0 | .0318 | .2173 | .20 | .1993 | 12.9446 | .0546 |
| 1 | 3 | .1873 | 1.3876 | 7.0 | .0318 | .2275 | .20 | .1993 | 13.0350 | .0660 |
| 1 | 4 | .1873 | 1.6290 | 7.0 | .0318 | .2327 | .20 | .1993 | 13.2966 | .0812 |
| 1 | 5 | .1873 | 1.9193 | 7.0 | .0318 | .2427 | .20 | .1993 | 13.5301 | .0957 |
| 1 | 6 | .1873 | 2.1041 | 7.0 | .0318 | .2581 | .20 | .1993 | 13.4858 | .0959 |
| 2 | 1 | .3103 | .9766 | 7.0 | .0500 | .2017 | .20 | .1993 | 12.7294 | .0485 |
| 2 | 2 | .3103 | 1.1312 | 7.0 | .0500 | .2173 | .20 | .1993 | 12.6635 | .0459 |
| 2 | 3 | .3103 | 1.3876 | 7.0 | .0500 | .2275 | .20 | .1993 | 12.8515 | .0573 |
| 2 | 4 | .3103 | 1.6290 | 7.0 | .0500 | .2327 | .20 | .1993 | 13.1074 | .0785 |
| 2 | 5 | .3103 | 1.9193 | 7.0 | .0500 | .2427 | .20 | .1993 | 13.3375 | .0870 |
| 2 | 6 | .3103 | 2.1041 | 7.0 | .0500 | .2581 | .20 | .1993 | 13.3084 | .0872 |
| 3 | 1 | .3896 | .9766 | 7.0 | .0644 | .2017 | .20 | .1993 | 12.5882 | .0418 |
| 3 | 2 | .3896 | 1.1312 | 7.0 | .0644 | .2173 | .20 | .1993 | 12.5268 | .0390 |
| 3 | 3 | .3896 | 1.3876 | 7.0 | .0644 | .2275 | .20 | .1993 | 12.7189 | .0505 |
| 3 | 4 | .3896 | 1.6290 | 7.0 | .0644 | .2327 | .20 | .1993 | 12.9846 | .0657 |
| 3 | 5 | .3896 | 1.9193 | 7.0 | .0644 | .2427 | .20 | .1993 | 13.1821 | .0802 |
| 3 | 6 | .3896 | 2.1041 | 7.0 | .0644 | .2581 | .20 | .1993 | 13.1666 | .0804 |
| 4 | 1 | .5194 | .9766 | 7.0 | .0837 | .2017 | .20 | .1993 | 12.4083 | .0324 |
| 4 | 2 | .5194 | 1.1312 | 7.0 | .0837 | .2173 | .20 | .1993 | 12.3527 | .0299 |
| 4 | 3 | .5194 | 1.3876 | 7.0 | .0837 | .2275 | .20 | .1993 | 12.5362 | .0413 |
| 4 | 4 | .5194 | 1.6290 | 7.0 | .0837 | .2327 | .20 | .1993 | 12.7924 | .0565 |
| 4 | 5 | .5194 | 1.9193 | 7.0 | .0837 | .2427 | .20 | .1993 | 13.0063 | .0710 |
| 4 | 6 | .5194 | 2.1041 | 7.0 | .0837 | .2581 | .20 | .1993 | 12.9654 | .0712 |
| 5 | 1 | .6361 | .9766 | 7.0 | .1025 | .2017 | .20 | .1993 | 12.2426 | .0235 |
| 5 | 2 | .6361 | 1.1312 | 7.0 | .1025 | .2173 | .20 | .1993 | 12.1920 | .0209 |
| 5 | 3 | .6361 | 1.3876 | 7.0 | .1025 | .2275 | .20 | .1993 | 12.3730 | .0323 |
| 5 | 4 | .6361 | 1.6290 | 7.0 | .1025 | .2327 | .20 | .1993 | 12.6141 | .0475 |
| 5 | 5 | .6361 | 1.9193 | 7.0 | .1025 | .2427 | .20 | .1993 | 12.8346 | .0620 |
| 5 | 6 | .6361 | 2.1041 | 7.0 | .1025 | .2581 | .20 | .1993 | 12.8177 | .0622 |
| 6 | 1 | .7031 | .9766 | 7.0 | .1133 | .2017 | .20 | .1993 | 12.1513 | .0183 |
| 6 | 2 | .7031 | 1.1312 | 7.0 | .1133 | .2173 | .20 | .1993 | 12.1034 | .0158 |
| 6 | 3 | .7031 | 1.3876 | 7.0 | .1133 | .2275 | .20 | .1993 | 12.2830 | .0272 |
| 6 | 4 | .7031 | 1.6290 | 7.0 | .1133 | .2327 | .20 | .1993 | 12.5212 | .0424 |
| 6 | 5 | .7031 | 1.9193 | 7.0 | .1133 | .2427 | .20 | .1993 | 12.7398 | .0569 |
| 6 | 6 | .7031 | 2.1041 | 7.0 | .1133 | .2581 | .20 | .1993 | 12.7250 | .0571 |
| 7 | 1 | .7912 | .9766 | 7.0 | .1275 | .2017 | .20 | .1993 | 12.0354 | .0115 |
| 7 | 2 | .7912 | 1.1312 | 7.0 | .1275 | .2173 | .20 | .1993 | 11.9908 | .0090 |
| 7 | 3 | .7912 | 1.3876 | 7.0 | .1275 | .2275 | .20 | .1993 | 12.1686 | .0204 |
| 7 | 4 | .7912 | 1.6290 | 7.0 | .1275 | .2327 | .20 | .1993 | 12.4031 | .0356 |
| 7 | 5 | .7912 | 1.9193 | 7.0 | .1275 | .2427 | .20 | .1993 | 12.6192 | .0501 |
| 7 | 6 | .7912 | 2.1041 | 7.0 | .1275 | .2581 | .20 | .1993 | 12.6070 | .0503 |
| 8 | 1 | .9091 | .9766 | 7.0 | .1465 | .2017 | .20 | .1993 | 11.8872 | .0025 |
| 8 | 2 | .9091 | 1.1312 | 7.0 | .1465 | .2173 | .20 | .1993 | 11.8468 | .0000 |
| 8 | 3 | .9091 | 1.3876 | 7.0 | .1465 | .2275 | .20 | .1993 | 12.0221 | .0114 |
| 8 | 4 | .9091 | 1.6290 | 7.0 | .1465 | .2327 | .20 | .1993 | 12.2518 | .0266 |
| 8 | 5 | .9091 | 1.9193 | 7.0 | .1465 | .2427 | .20 | .1993 | 12.4646 | .0411 |
| 8 | 6 | .9091 | 2.1041 | 7.0 | .1465 | .2581 | .20 | .1993 | 12.4557 | .0413 |
| 1 | TC | .1873 | .5600 | 7.0 | .0318 | .1229 | .20 | .1993 | 14.0023 | .1008 |
| 2 | TC | .3103 | .5600 | 7.0 | .0500 | .1229 | .20 | .1993 | 13.7544 | .0921 |
| 3 | TC | .3896 | .5600 | 7.0 | .0644 | .1229 | .20 | .1993 | 13.5690 | .0852 |
| 4 | TC | .5194 | .5600 | 7.0 | .0837 | .1229 | .20 | .1993 | 13.3345 | .0780 |
| 5 | TC | .6361 | .5600 | 7.0 | .1025 | .1229 | .20 | .1993 | 13.1200 | .0671 |
| 6 | TC | .7031 | .5600 | 7.0 | .1133 | .1229 | .20 | .1993 | 13.0025 | .0613 |
| 7 | TC | .7912 | .5600 | 7.0 | .1275 | .1229 | .20 | .1993 | 12.8538 | .0552 |

SPT/WINQ

MINIMUM SCALING FACTOR= 11.6829

| I | J | AF | AR | W2 | MF | MR | D1 | D2 | AJ | ND |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | .1973 | .9766 | 7.0 | .0318 | .2017 | .20 | .2100 | 12.7022 | .0561 |
| 1 | 2 | .1973 | 1.1312 | 7.0 | .0318 | .2173 | .20 | .2100 | 12.6361 | .0537 |
| 1 | 3 | .1973 | 1.3876 | 7.0 | .0318 | .2275 | .20 | .2100 | 12.8266 | .0655 |
| 1 | 4 | .1973 | 1.6290 | 7.0 | .0318 | .2327 | .20 | .2100 | 13.0856 | .0809 |
| 1 | 5 | .1973 | 1.9193 | 7.0 | .0318 | .2427 | .20 | .2100 | 13.3186 | .0958 |
| 1 | 6 | .1973 | 2.1041 | 7.0 | .0318 | .2581 | .20 | .2100 | 13.2696 | .0962 |
| 2 | 1 | .3103 | .9766 | 7.0 | .0500 | .2017 | .20 | .2100 | 12.5236 | .0476 |
| 2 | 2 | .3103 | 1.1312 | 7.0 | .0500 | .2173 | .20 | .2100 | 12.4634 | .0452 |
| 2 | 3 | .3103 | 1.3876 | 7.0 | .0500 | .2275 | .20 | .2100 | 12.6514 | .0569 |
| 2 | 4 | .3103 | 1.6290 | 7.0 | .0500 | .2327 | .20 | .2100 | 12.8050 | .0724 |
| 2 | 5 | .3103 | 1.9193 | 7.0 | .0500 | .2427 | .20 | .2100 | 13.1344 | .0873 |
| 2 | 6 | .3103 | 2.1041 | 7.0 | .0500 | .2581 | .20 | .2100 | 13.1101 | .0877 |
| 3 | 1 | .3886 | .9766 | 7.0 | .0644 | .2017 | .20 | .2100 | 12.3889 | .0406 |
| 3 | 2 | .3886 | 1.1312 | 7.0 | .0644 | .2173 | .20 | .2100 | 12.3330 | .0384 |
| 3 | 3 | .3886 | 1.3876 | 7.0 | .0644 | .2275 | .20 | .2100 | 12.5191 | .0502 |
| 3 | 4 | .3886 | 1.6290 | 7.0 | .0644 | .2327 | .20 | .2100 | 12.7684 | .0657 |
| 3 | 5 | .3886 | 1.9193 | 7.0 | .0644 | .2427 | .20 | .2100 | 12.8852 | .0805 |
| 3 | 6 | .3886 | 2.1041 | 7.0 | .0644 | .2581 | .20 | .2100 | 12.9743 | .0809 |
| 4 | 1 | .5184 | .9766 | 7.0 | .0837 | .2017 | .20 | .2100 | 12.2174 | .0318 |
| 4 | 2 | .5184 | 1.1312 | 7.0 | .0837 | .2173 | .20 | .2100 | 12.1666 | .0294 |
| 4 | 3 | .5184 | 1.3876 | 7.0 | .0837 | .2275 | .20 | .2100 | 12.3502 | .0411 |
| 4 | 4 | .5184 | 1.6290 | 7.0 | .0837 | .2327 | .20 | .2100 | 12.5941 | .0566 |
| 4 | 5 | .5184 | 1.9193 | 7.0 | .0837 | .2427 | .20 | .2100 | 12.8173 | .0715 |
| 4 | 6 | .5184 | 2.1041 | 7.0 | .0837 | .2581 | .20 | .2100 | 12.8006 | .0718 |
| 5 | 1 | .6361 | .9766 | 7.0 | .1025 | .2017 | .20 | .2100 | 12.0592 | .0230 |
| 5 | 2 | .6361 | 1.1312 | 7.0 | .1025 | .2173 | .20 | .2100 | 12.0132 | .0206 |
| 5 | 3 | .6361 | 1.3876 | 7.0 | .1025 | .2275 | .20 | .2100 | 12.1841 | .0323 |
| 5 | 4 | .6361 | 1.6290 | 7.0 | .1025 | .2327 | .20 | .2100 | 12.4330 | .0478 |
| 5 | 5 | .6361 | 1.9193 | 7.0 | .1025 | .2427 | .20 | .2100 | 12.6528 | .0626 |
| 5 | 6 | .6361 | 2.1041 | 7.0 | .1025 | .2581 | .20 | .2100 | 12.6397 | .0631 |
| 6 | 1 | .7031 | .9766 | 7.0 | .1133 | .2017 | .20 | .2100 | 11.9720 | .0179 |
| 6 | 2 | .7031 | 1.1312 | 7.0 | .1133 | .2173 | .20 | .2100 | 11.9285 | .0155 |
| 6 | 3 | .7031 | 1.3876 | 7.0 | .1133 | .2275 | .20 | .2100 | 12.1080 | .0273 |
| 6 | 4 | .7031 | 1.6290 | 7.0 | .1133 | .2327 | .20 | .2100 | 12.3440 | .0427 |
| 6 | 5 | .7031 | 1.9193 | 7.0 | .1133 | .2427 | .20 | .2100 | 12.5618 | .0576 |
| 6 | 6 | .7031 | 2.1041 | 7.0 | .1133 | .2581 | .20 | .2100 | 12.5506 | .0580 |
| 7 | 1 | .7812 | .9766 | 7.0 | .1275 | .2017 | .20 | .2100 | 11.8612 | .0112 |
| 7 | 2 | .7812 | 1.1312 | 7.0 | .1275 | .2173 | .20 | .2100 | 11.8206 | .0089 |
| 7 | 3 | .7812 | 1.3876 | 7.0 | .1275 | .2275 | .20 | .2100 | 11.9884 | .0206 |
| 7 | 4 | .7812 | 1.6290 | 7.0 | .1275 | .2327 | .20 | .2100 | 12.2308 | .0361 |
| 7 | 5 | .7812 | 1.9193 | 7.0 | .1275 | .2427 | .20 | .2100 | 12.4461 | .0508 |
| 7 | 6 | .7812 | 2.1041 | 7.0 | .1275 | .2581 | .20 | .2100 | 12.4375 | .0513 |
| 8 | 1 | .9081 | .9766 | 7.0 | .1465 | .2017 | .20 | .2100 | 11.7184 | .0023 |
| 8 | 2 | .9081 | 1.1312 | 7.0 | .1465 | .2173 | .20 | .2100 | 11.6829 | .0000 |
| 8 | 3 | .9081 | 1.3876 | 7.0 | .1465 | .2275 | .20 | .2100 | 11.8580 | .0117 |
| 8 | 4 | .9081 | 1.6290 | 7.0 | .1465 | .2327 | .20 | .2100 | 12.0857 | .0272 |
| 8 | 5 | .9081 | 1.9193 | 7.0 | .1465 | .2427 | .20 | .2100 | 12.2977 | .0420 |
| 8 | 6 | .9081 | 2.1041 | 7.0 | .1465 | .2581 | .20 | .2100 | 12.2821 | .0424 |
| 1 | TC | .1973 | .5600 | 7.0 | .0318 | .1229 | .20 | .2100 | 13.7370 | .0892 |
| 2 | TC | .3103 | .5600 | 7.0 | .0500 | .1229 | .20 | .2100 | 13.5018 | .0807 |
| 3 | TC | .3886 | .5600 | 7.0 | .0644 | .1229 | .20 | .2100 | 13.3258 | .0840 |
| 4 | TC | .5184 | .5600 | 7.0 | .0837 | .1229 | .20 | .2100 | 13.1031 | .0749 |
| 5 | TC | .6361 | .5600 | 7.0 | .1025 | .1229 | .20 | .2100 | 12.8981 | .0661 |
| 6 | TC | .7031 | .5600 | 7.0 | .1133 | .1229 | .20 | .2100 | 12.7872 | .0610 |
| 7 | TC | .7812 | .5600 | 7.0 | .1275 | .1229 | .20 | .2100 | 12.6456 | .0544 |

DDATE/RANDOM

MINIMUM SCALING FACTOR= 11.8576

| I | J | AF | AR | W2 | MF | MR | D1 | D2 | AJ | NO |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | .1873 | .9766 | 7.0 | .0318 | .2017 | .20 | .1986 | 12.9313 | .0572 |
| 1 | 2 | .1873 | 1.1312 | 7.0 | .0318 | .2173 | .20 | .1986 | 12.8585 | .0546 |
| 1 | 3 | .1873 | 1.3876 | 7.0 | .0318 | .2275 | .20 | .1986 | 13.0489 | .0680 |
| 1 | 4 | .1873 | 1.6280 | 7.0 | .0318 | .2327 | .20 | .1986 | 13.3180 | .0812 |
| 1 | 5 | .1873 | 1.8183 | 7.0 | .0318 | .2427 | .20 | .1986 | 13.5441 | .0957 |
| 1 | 6 | .1873 | 2.1041 | 7.0 | .0318 | .2581 | .20 | .1986 | 13.5098 | .0959 |
| 2 | 1 | .3103 | .9766 | 7.0 | .0500 | .2017 | .20 | .1986 | 12.7431 | .0485 |
| 2 | 2 | .3103 | 1.1312 | 7.0 | .0500 | .2173 | .20 | .1986 | 12.6768 | .0480 |
| 2 | 3 | .3103 | 1.3876 | 7.0 | .0500 | .2275 | .20 | .1986 | 12.8840 | .0574 |
| 2 | 4 | .3103 | 1.6280 | 7.0 | .0500 | .2327 | .20 | .1986 | 13.1209 | .0725 |
| 2 | 5 | .3103 | 1.8183 | 7.0 | .0500 | .2427 | .20 | .1986 | 13.3510 | .0870 |
| 2 | 6 | .3103 | 2.1041 | 7.0 | .0500 | .2581 | .20 | .1986 | 13.3216 | .0872 |
| 3 | 1 | .3886 | .9766 | 7.0 | .0644 | .2017 | .20 | .1986 | 12.6614 | .0416 |
| 3 | 2 | .3886 | 1.1312 | 7.0 | .0644 | .2173 | .20 | .1986 | 12.5387 | .0391 |
| 3 | 3 | .3886 | 1.3876 | 7.0 | .0644 | .2275 | .20 | .1986 | 12.7250 | .0505 |
| 3 | 4 | .3886 | 1.6280 | 7.0 | .0644 | .2327 | .20 | .1986 | 12.8777 | .0657 |
| 3 | 5 | .3886 | 1.8183 | 7.0 | .0644 | .2427 | .20 | .1986 | 13.2051 | .0802 |
| 3 | 6 | .3886 | 2.1041 | 7.0 | .0644 | .2581 | .20 | .1986 | 13.1794 | .0803 |
| 4 | 1 | .5194 | .9766 | 7.0 | .0837 | .2017 | .20 | .1986 | 12.4210 | .0325 |
| 4 | 2 | .5194 | 1.1312 | 7.0 | .0837 | .2173 | .20 | .1986 | 12.3650 | .0289 |
| 4 | 3 | .5194 | 1.3876 | 7.0 | .0837 | .2275 | .20 | .1986 | 12.5486 | .0413 |
| 4 | 4 | .5194 | 1.6280 | 7.0 | .0837 | .2327 | .20 | .1986 | 12.7849 | .0565 |
| 4 | 5 | .5194 | 1.8183 | 7.0 | .0837 | .2427 | .20 | .1986 | 13.0188 | .0710 |
| 4 | 6 | .5194 | 2.1041 | 7.0 | .0837 | .2581 | .20 | .1986 | 12.9977 | .0711 |
| 5 | 1 | .6361 | .9766 | 7.0 | .1025 | .2017 | .20 | .1986 | 12.2548 | .0235 |
| 5 | 2 | .6361 | 1.1312 | 7.0 | .1025 | .2173 | .20 | .1986 | 12.2039 | .0209 |
| 5 | 3 | .6361 | 1.3876 | 7.0 | .1025 | .2275 | .20 | .1986 | 12.3849 | .0324 |
| 5 | 4 | .6361 | 1.6280 | 7.0 | .1025 | .2327 | .20 | .1986 | 12.6261 | .0475 |
| 5 | 5 | .6361 | 1.8183 | 7.0 | .1025 | .2427 | .20 | .1986 | 12.8467 | .0620 |
| 5 | 6 | .6361 | 2.1041 | 7.0 | .1025 | .2581 | .20 | .1986 | 12.8285 | .0622 |
| 6 | 1 | .7031 | .9766 | 7.0 | .1133 | .2017 | .20 | .1986 | 12.1832 | .0183 |
| 6 | 2 | .7031 | 1.1312 | 7.0 | .1133 | .2173 | .20 | .1986 | 12.1150 | .0153 |
| 6 | 3 | .7031 | 1.3876 | 7.0 | .1133 | .2275 | .20 | .1986 | 12.2946 | .0272 |
| 6 | 4 | .7031 | 1.6280 | 7.0 | .1133 | .2327 | .20 | .1986 | 12.5330 | .0424 |
| 6 | 5 | .7031 | 1.8183 | 7.0 | .1133 | .2427 | .20 | .1986 | 12.7516 | .0568 |
| 6 | 6 | .7031 | 2.1041 | 7.0 | .1133 | .2581 | .20 | .1986 | 12.7360 | .0570 |
| 7 | 1 | .7812 | .9766 | 7.0 | .1275 | .2017 | .20 | .1986 | 12.0469 | .0116 |
| 7 | 2 | .7812 | 1.1312 | 7.0 | .1275 | .2173 | .20 | .1986 | 12.0021 | .0080 |
| 7 | 3 | .7812 | 1.3876 | 7.0 | .1275 | .2275 | .20 | .1986 | 12.1789 | .0204 |
| 7 | 4 | .7812 | 1.6280 | 7.0 | .1275 | .2327 | .20 | .1986 | 12.4146 | .0356 |
| 7 | 5 | .7812 | 1.8183 | 7.0 | .1275 | .2427 | .20 | .1986 | 12.6307 | .0501 |
| 7 | 6 | .7812 | 2.1041 | 7.0 | .1275 | .2581 | .20 | .1986 | 12.6183 | .0503 |
| 8 | 1 | .8081 | .9766 | 7.0 | .1465 | .2017 | .20 | .1986 | 11.8883 | .0025 |
| 8 | 2 | .8081 | 1.1312 | 7.0 | .1465 | .2173 | .20 | .1986 | 11.8576 | .0000 |
| 8 | 3 | .8081 | 1.3876 | 7.0 | .1465 | .2275 | .20 | .1986 | 12.0330 | .0114 |
| 8 | 4 | .8081 | 1.6280 | 7.0 | .1465 | .2327 | .20 | .1986 | 12.2629 | .0265 |
| 8 | 5 | .8081 | 1.8183 | 7.0 | .1465 | .2427 | .20 | .1986 | 12.4757 | .0410 |
| 8 | 6 | .8081 | 2.1041 | 7.0 | .1465 | .2581 | .20 | .1986 | 12.4666 | .0412 |
| 1 | TC | .1873 | .5600 | 7.0 | .0318 | .1229 | .20 | .1986 | 14.0200 | .1009 |
| 2 | TC | .3103 | .5600 | 7.0 | .0500 | .1229 | .20 | .1986 | 13.7713 | .0922 |
| 3 | TC | .3886 | .5600 | 7.0 | .0644 | .1229 | .20 | .1986 | 13.5852 | .0853 |
| 4 | TC | .5194 | .5600 | 7.0 | .0837 | .1229 | .20 | .1986 | 13.3499 | .0761 |
| 5 | TC | .6361 | .5600 | 7.0 | .1025 | .1229 | .20 | .1986 | 13.1347 | .0672 |
| 6 | TC | .7031 | .5600 | 7.0 | .1133 | .1229 | .20 | .1986 | 13.0168 | .0620 |
| 7 | TC | .7812 | .5600 | 7.0 | .1275 | .1229 | .20 | .1986 | 12.8677 | .0552 |

ODATE/FMFS

MINIMUM SCALING FACTOR= 11.9675

| I | J | AF | AR | WR | MF | MR | D1 | D2 | AJ | ND |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | .1973 | .9766 | 7.0 | .0318 | .2017 | .20 | .1916 | 13.0761 | .0579 |
| 1 | 2 | .1973 | 1.1312 | 7.0 | .0318 | .2173 | .20 | .1916 | 12.9990 | .0552 |
| 1 | 3 | .1973 | 1.3876 | 7.0 | .0318 | .2275 | .20 | .1916 | 13.1692 | .0664 |
| 1 | 4 | .1973 | 1.6290 | 7.0 | .0318 | .2327 | .20 | .1916 | 13.4526 | .0814 |
| 1 | 5 | .1973 | 1.9193 | 7.0 | .0318 | .2427 | .20 | .1916 | 13.6665 | .0956 |
| 1 | 6 | .1973 | 2.1041 | 7.0 | .0318 | .2581 | .20 | .1916 | 13.6484 | .0957 |
| 2 | 1 | .3103 | .9766 | 7.0 | .0500 | .2017 | .20 | .1916 | 12.8678 | .0491 |
| 2 | 2 | .3103 | 1.1312 | 7.0 | .0500 | .2173 | .20 | .1916 | 12.8115 | .0464 |
| 2 | 3 | .3103 | 1.3876 | 7.0 | .0500 | .2275 | .20 | .1916 | 12.9994 | .0576 |
| 2 | 4 | .3103 | 1.6290 | 7.0 | .0500 | .2327 | .20 | .1916 | 13.2571 | .0786 |
| 2 | 5 | .3103 | 1.9193 | 7.0 | .0500 | .2427 | .20 | .1916 | 13.4678 | .0869 |
| 2 | 6 | .3103 | 2.1041 | 7.0 | .0500 | .2581 | .20 | .1916 | 13.4549 | .0868 |
| 3 | 1 | .3986 | .9766 | 7.0 | .0644 | .2017 | .20 | .1916 | 12.7355 | .0422 |
| 3 | 2 | .3986 | 1.1312 | 7.0 | .0644 | .2173 | .20 | .1916 | 12.6701 | .0395 |
| 3 | 3 | .3986 | 1.3876 | 7.0 | .0644 | .2275 | .20 | .1916 | 12.8561 | .0507 |
| 3 | 4 | .3986 | 1.6290 | 7.0 | .0644 | .2327 | .20 | .1916 | 13.1086 | .0657 |
| 3 | 5 | .3986 | 1.9193 | 7.0 | .0644 | .2427 | .20 | .1916 | 13.3374 | .0799 |
| 3 | 6 | .3986 | 2.1041 | 7.0 | .0644 | .2581 | .20 | .1916 | 13.3086 | .0800 |
| 4 | 1 | .5194 | .9766 | 7.0 | .0837 | .2017 | .20 | .1916 | 12.5464 | .0329 |
| 4 | 2 | .5194 | 1.1312 | 7.0 | .0837 | .2173 | .20 | .1916 | 12.4900 | .0302 |
| 4 | 3 | .5194 | 1.3876 | 7.0 | .0837 | .2275 | .20 | .1916 | 12.6735 | .0414 |
| 4 | 4 | .5194 | 1.6290 | 7.0 | .0837 | .2327 | .20 | .1916 | 12.9214 | .0564 |
| 4 | 5 | .5194 | 1.9193 | 7.0 | .0837 | .2427 | .20 | .1916 | 13.1458 | .0706 |
| 4 | 6 | .5194 | 2.1041 | 7.0 | .0837 | .2581 | .20 | .1916 | 13.1217 | .0707 |
| 5 | 1 | .6361 | .9766 | 7.0 | .1025 | .2017 | .20 | .1916 | 12.3761 | .0236 |
| 5 | 2 | .6361 | 1.1312 | 7.0 | .1025 | .2173 | .20 | .1916 | 12.3240 | .0211 |
| 5 | 3 | .6361 | 1.3876 | 7.0 | .1025 | .2275 | .20 | .1916 | 12.6061 | .0324 |
| 5 | 4 | .6361 | 1.6290 | 7.0 | .1025 | .2327 | .20 | .1916 | 12.7477 | .0473 |
| 5 | 5 | .6361 | 1.9193 | 7.0 | .1025 | .2427 | .20 | .1916 | 12.9687 | .0616 |
| 5 | 6 | .6361 | 2.1041 | 7.0 | .1025 | .2581 | .20 | .1916 | 12.9489 | .0616 |
| 6 | 1 | .7031 | .9766 | 7.0 | .1133 | .2017 | .20 | .1916 | 12.2837 | .0136 |
| 6 | 2 | .7031 | 1.1312 | 7.0 | .1133 | .2173 | .20 | .1916 | 12.2324 | .0159 |
| 6 | 3 | .7031 | 1.3876 | 7.0 | .1133 | .2275 | .20 | .1916 | 12.4122 | .0272 |
| 6 | 4 | .7031 | 1.6290 | 7.0 | .1133 | .2327 | .20 | .1916 | 12.6519 | .0421 |
| 6 | 5 | .7031 | 1.9193 | 7.0 | .1133 | .2427 | .20 | .1916 | 12.8710 | .0564 |
| 6 | 6 | .7031 | 2.1041 | 7.0 | .1133 | .2581 | .20 | .1916 | 12.8534 | .0564 |
| 7 | 1 | .7812 | .9766 | 7.0 | .1275 | .2017 | .20 | .1916 | 12.1638 | .0118 |
| 7 | 2 | .7812 | 1.1312 | 7.0 | .1275 | .2173 | .20 | .1916 | 12.1162 | .0061 |
| 7 | 3 | .7812 | 1.3876 | 7.0 | .1275 | .2275 | .20 | .1916 | 12.2941 | .0203 |
| 7 | 4 | .7812 | 1.6290 | 7.0 | .1275 | .2327 | .20 | .1916 | 12.5301 | .0353 |
| 7 | 5 | .7812 | 1.9193 | 7.0 | .1275 | .2427 | .20 | .1916 | 12.7467 | .0496 |
| 7 | 6 | .7812 | 2.1041 | 7.0 | .1275 | .2581 | .20 | .1916 | 12.7319 | .0496 |
| 8 | 1 | .9091 | .9766 | 7.0 | .1465 | .2017 | .20 | .1916 | 12.0109 | .0026 |
| 8 | 2 | .9091 | 1.1312 | 7.0 | .1465 | .2173 | .20 | .1916 | 11.9675 | .0000 |
| 8 | 3 | .9091 | 1.3876 | 7.0 | .1465 | .2275 | .20 | .1916 | 12.1430 | .0112 |
| 8 | 4 | .9091 | 1.6290 | 7.0 | .1465 | .2327 | .20 | .1916 | 12.3742 | .0262 |
| 8 | 5 | .9091 | 1.9193 | 7.0 | .1465 | .2427 | .20 | .1916 | 12.5876 | .0404 |
| 8 | 6 | .9091 | 2.1041 | 7.0 | .1465 | .2581 | .20 | .1916 | 12.5762 | .0404 |
| 1 | TC | .1973 | .5600 | 7.0 | .0318 | .1229 | .20 | .1916 | 14.1997 | .1018 |
| 2 | TC | .3103 | .5600 | 7.0 | .0500 | .1229 | .20 | .1916 | 13.9420 | .0931 |
| 3 | TC | .3986 | .5600 | 7.0 | .0644 | .1229 | .20 | .1916 | 13.7495 | .0862 |
| 4 | TC | .5194 | .5600 | 7.0 | .0837 | .1229 | .20 | .1916 | 13.5061 | .0763 |
| 5 | TC | .6361 | .5600 | 7.0 | .1025 | .1229 | .20 | .1916 | 13.2837 | .0678 |
| 6 | TC | .7031 | .5600 | 7.0 | .1133 | .1229 | .20 | .1916 | 13.1619 | .0626 |
| 7 | TC | .7812 | .5600 | 7.0 | .1275 | .1229 | .20 | .1916 | 13.0080 | .0556 |

DDATE/NINO

MINIMUM SCALING FACTOR= 11.7589

| I | J | AF | AR | WE | MF | MR | D1 | D2 | AJ | ND |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | .1973 | .9766 | 7.0 | .0318 | .2017 | .20 | .2050 | 12.8017 | .0566 |
| 1 | 2 | .1973 | 1.1312 | 7.0 | .0318 | .2173 | .20 | .2050 | 12.7327 | .0541 |
| 1 | 3 | .1973 | 1.3876 | 7.0 | .0318 | .2275 | .20 | .2050 | 12.9232 | .0657 |
| 1 | 4 | .1973 | 1.6280 | 7.0 | .0318 | .2327 | .20 | .2050 | 13.1034 | .0811 |
| 1 | 5 | .1973 | 1.8193 | 7.0 | .0318 | .2427 | .20 | .2050 | 13.4168 | .0957 |
| 1 | 6 | .1973 | 2.1041 | 7.0 | .0318 | .2581 | .20 | .2050 | 13.3852 | .0961 |
| 2 | 1 | .3103 | .9766 | 7.0 | .0500 | .2017 | .20 | .2050 | 12.6190 | .0480 |
| 2 | 2 | .3103 | 1.1312 | 7.0 | .0500 | .2173 | .20 | .2050 | 12.5561 | .0455 |
| 2 | 3 | .3103 | 1.3876 | 7.0 | .0500 | .2275 | .20 | .2050 | 12.7441 | .0571 |
| 2 | 4 | .3103 | 1.6280 | 7.0 | .0500 | .2327 | .20 | .2050 | 12.9868 | .0725 |
| 2 | 5 | .3103 | 1.8193 | 7.0 | .0500 | .2427 | .20 | .2050 | 13.2286 | .0872 |
| 2 | 6 | .3103 | 2.1041 | 7.0 | .0500 | .2581 | .20 | .2050 | 13.2026 | .0875 |
| 3 | 1 | .3886 | .9766 | 7.0 | .0644 | .2017 | .20 | .2050 | 12.4812 | .0412 |
| 3 | 2 | .3886 | 1.1312 | 7.0 | .0644 | .2173 | .20 | .2050 | 12.4226 | .0387 |
| 3 | 3 | .3886 | 1.3876 | 7.0 | .0644 | .2275 | .20 | .2050 | 12.6089 | .0503 |
| 3 | 4 | .3886 | 1.6280 | 7.0 | .0644 | .2327 | .20 | .2050 | 12.8594 | .0657 |
| 3 | 5 | .3886 | 1.8193 | 7.0 | .0644 | .2427 | .20 | .2050 | 13.0665 | .0803 |
| 3 | 6 | .3886 | 2.1041 | 7.0 | .0644 | .2581 | .20 | .2050 | 13.0635 | .0807 |
| 4 | 1 | .5184 | .9766 | 7.0 | .0837 | .2017 | .20 | .2050 | 12.3059 | .0321 |
| 4 | 2 | .5184 | 1.1312 | 7.0 | .0837 | .2173 | .20 | .2050 | 12.2528 | .0298 |
| 4 | 3 | .5184 | 1.3876 | 7.0 | .0837 | .2275 | .20 | .2050 | 12.4364 | .0412 |
| 4 | 4 | .5184 | 1.6280 | 7.0 | .0837 | .2327 | .20 | .2050 | 12.6814 | .0565 |
| 4 | 5 | .5184 | 1.8193 | 7.0 | .0837 | .2427 | .20 | .2050 | 12.9049 | .0712 |
| 4 | 6 | .5184 | 2.1041 | 7.0 | .0837 | .2581 | .20 | .2050 | 12.8863 | .0716 |
| 5 | 1 | .6361 | .9766 | 7.0 | .1025 | .2017 | .20 | .2050 | 12.1442 | .0232 |
| 5 | 2 | .6361 | 1.1312 | 7.0 | .1025 | .2173 | .20 | .2050 | 12.0861 | .0207 |
| 5 | 3 | .6361 | 1.3876 | 7.0 | .1025 | .2275 | .20 | .2050 | 12.2771 | .0323 |
| 5 | 4 | .6361 | 1.6280 | 7.0 | .1025 | .2327 | .20 | .2050 | 12.5170 | .0477 |
| 5 | 5 | .6361 | 1.8193 | 7.0 | .1025 | .2427 | .20 | .2050 | 12.7371 | .0624 |
| 5 | 6 | .6361 | 2.1041 | 7.0 | .1025 | .2581 | .20 | .2050 | 12.7223 | .0627 |
| 6 | 1 | .7031 | .9766 | 7.0 | .1133 | .2017 | .20 | .2050 | 12.0551 | .0181 |
| 6 | 2 | .7031 | 1.1312 | 7.0 | .1133 | .2173 | .20 | .2050 | 12.0086 | .0156 |
| 6 | 3 | .7031 | 1.3876 | 7.0 | .1133 | .2275 | .20 | .2050 | 12.1881 | .0272 |
| 6 | 4 | .7031 | 1.6280 | 7.0 | .1133 | .2327 | .20 | .2050 | 12.4262 | .0426 |
| 6 | 5 | .7031 | 1.8193 | 7.0 | .1133 | .2427 | .20 | .2050 | 12.6444 | .0573 |
| 6 | 6 | .7031 | 2.1041 | 7.0 | .1133 | .2581 | .20 | .2050 | 12.6316 | .0576 |
| 7 | 1 | .7812 | .9766 | 7.0 | .1275 | .2017 | .20 | .2050 | 11.8418 | .0114 |
| 7 | 2 | .7812 | 1.1312 | 7.0 | .1275 | .2173 | .20 | .2050 | 11.8887 | .0088 |
| 7 | 3 | .7812 | 1.3876 | 7.0 | .1275 | .2275 | .20 | .2050 | 12.0773 | .0205 |
| 7 | 4 | .7812 | 1.6280 | 7.0 | .1275 | .2327 | .20 | .2050 | 12.3107 | .0359 |
| 7 | 5 | .7812 | 1.8193 | 7.0 | .1275 | .2427 | .20 | .2050 | 12.5264 | .0506 |
| 7 | 6 | .7812 | 2.1041 | 7.0 | .1275 | .2581 | .20 | .2050 | 12.5161 | .0509 |
| 8 | 1 | .8081 | .9766 | 7.0 | .1465 | .2017 | .20 | .2050 | 11.7872 | .0024 |
| 8 | 2 | .8081 | 1.1312 | 7.0 | .1465 | .2173 | .20 | .2050 | 11.7589 | .0000 |
| 8 | 3 | .8081 | 1.3876 | 7.0 | .1465 | .2275 | .20 | .2050 | 11.9341 | .0116 |
| 8 | 4 | .8081 | 1.6280 | 7.0 | .1465 | .2327 | .20 | .2050 | 12.1628 | .0269 |
| 8 | 5 | .8081 | 1.8193 | 7.0 | .1465 | .2427 | .20 | .2050 | 12.3752 | .0416 |
| 8 | 6 | .8081 | 2.1041 | 7.0 | .1465 | .2581 | .20 | .2050 | 12.3680 | .0419 |
| 1 | TC | .1973 | .5600 | 7.0 | .0318 | .1229 | .20 | .2050 | 13.8597 | .0939 |
| 2 | TC | .3103 | .5600 | 7.0 | .0500 | .1229 | .20 | .2050 | 13.6187 | .0914 |
| 3 | TC | .3886 | .5600 | 7.0 | .0644 | .1229 | .20 | .2050 | 13.4384 | .0846 |
| 4 | TC | .5184 | .5600 | 7.0 | .0837 | .1229 | .20 | .2050 | 13.2102 | .0754 |
| 5 | TC | .6361 | .5600 | 7.0 | .1025 | .1229 | .20 | .2050 | 13.0014 | .0666 |
| 6 | TC | .7031 | .5600 | 7.0 | .1133 | .1229 | .20 | .2050 | 12.8869 | .0615 |
| 7 | TC | .7812 | .5600 | 7.0 | .1275 | .1229 | .20 | .2050 | 12.7421 | .0548 |

ODATE/WING

MINIMUM SCALING FACTOR= 11.6064

| I | J | AF | AR | WR | MF | MR | D1 | D2 | AJ | ND |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | .1973 | .9766 | 7.0 | .0318 | .2017 | .20 | .2151 | 12.6023 | .0558 |
| 1 | 2 | .1973 | 1.1312 | 7.0 | .0318 | .2173 | .20 | .2151 | 12.5391 | .0533 |
| 1 | 3 | .1973 | 1.3876 | 7.0 | .0318 | .2275 | .20 | .2151 | 12.7296 | .0652 |
| 1 | 4 | .1973 | 1.6290 | 7.0 | .0318 | .2327 | .20 | .2151 | 12.9074 | .0808 |
| 1 | 5 | .1973 | 1.9193 | 7.0 | .0318 | .2427 | .20 | .2151 | 13.2201 | .0858 |
| 1 | 6 | .1973 | 2.1041 | 7.0 | .0318 | .2581 | .20 | .2151 | 13.1934 | .0864 |
| 2 | 1 | .3103 | .9766 | 7.0 | .0500 | .2017 | .20 | .2151 | 12.4278 | .0471 |
| 2 | 2 | .3103 | 1.1312 | 7.0 | .0500 | .2173 | .20 | .2151 | 12.3703 | .0449 |
| 2 | 3 | .3103 | 1.3876 | 7.0 | .0500 | .2275 | .20 | .2151 | 12.5593 | .0568 |
| 2 | 4 | .3103 | 1.6290 | 7.0 | .0500 | .2327 | .20 | .2151 | 12.8166 | .0724 |
| 2 | 5 | .3103 | 1.9193 | 7.0 | .0500 | .2427 | .20 | .2151 | 13.0398 | .0874 |
| 2 | 6 | .3103 | 2.1041 | 7.0 | .0500 | .2581 | .20 | .2151 | 13.0176 | .0879 |
| 3 | 1 | .3886 | .9766 | 7.0 | .0644 | .2017 | .20 | .2151 | 12.2862 | .0404 |
| 3 | 2 | .3886 | 1.1312 | 7.0 | .0644 | .2173 | .20 | .2151 | 12.2428 | .0382 |
| 3 | 3 | .3886 | 1.3876 | 7.0 | .0644 | .2275 | .20 | .2151 | 12.4288 | .0500 |
| 3 | 4 | .3886 | 1.6290 | 7.0 | .0644 | .2327 | .20 | .2151 | 12.6770 | .0656 |
| 3 | 5 | .3886 | 1.9193 | 7.0 | .0644 | .2427 | .20 | .2151 | 12.8934 | .0807 |
| 3 | 6 | .3886 | 2.1041 | 7.0 | .0644 | .2581 | .20 | .2151 | 12.8846 | .0812 |
| 4 | 1 | .5184 | .9766 | 7.0 | .0837 | .2017 | .20 | .2151 | 12.1284 | .0315 |
| 4 | 2 | .5184 | 1.1312 | 7.0 | .0837 | .2173 | .20 | .2151 | 12.0681 | .0292 |
| 4 | 3 | .5184 | 1.3876 | 7.0 | .0837 | .2275 | .20 | .2151 | 12.2635 | .0411 |
| 4 | 4 | .5184 | 1.6290 | 7.0 | .0837 | .2327 | .20 | .2151 | 12.5063 | .0567 |
| 4 | 5 | .5184 | 1.9193 | 7.0 | .0837 | .2427 | .20 | .2151 | 12.7291 | .0717 |
| 4 | 6 | .5184 | 2.1041 | 7.0 | .0837 | .2581 | .20 | .2151 | 12.7143 | .0722 |
| 5 | 1 | .6361 | .9766 | 7.0 | .1025 | .2017 | .20 | .2151 | 11.9737 | .0227 |
| 5 | 2 | .6361 | 1.1312 | 7.0 | .1025 | .2173 | .20 | .2151 | 11.9299 | .0204 |
| 5 | 3 | .6361 | 1.3876 | 7.0 | .1025 | .2275 | .20 | .2151 | 12.1107 | .0323 |
| 5 | 4 | .6361 | 1.6290 | 7.0 | .1025 | .2327 | .20 | .2151 | 12.3485 | .0478 |
| 5 | 5 | .6361 | 1.9193 | 7.0 | .1025 | .2427 | .20 | .2151 | 12.5679 | .0629 |
| 5 | 6 | .6361 | 2.1041 | 7.0 | .1025 | .2581 | .20 | .2151 | 12.5566 | .0635 |
| 6 | 1 | .7031 | .9766 | 7.0 | .1133 | .2017 | .20 | .2151 | 11.8883 | .0177 |
| 6 | 2 | .7031 | 1.1312 | 7.0 | .1133 | .2173 | .20 | .2151 | 11.8468 | .0154 |
| 6 | 3 | .7031 | 1.3876 | 7.0 | .1133 | .2275 | .20 | .2151 | 12.0263 | .0273 |
| 6 | 4 | .7031 | 1.6290 | 7.0 | .1133 | .2327 | .20 | .2151 | 12.2613 | .0429 |
| 6 | 5 | .7031 | 1.9193 | 7.0 | .1133 | .2427 | .20 | .2151 | 12.4787 | .0579 |
| 6 | 6 | .7031 | 2.1041 | 7.0 | .1133 | .2581 | .20 | .2151 | 12.4634 | .0584 |
| 7 | 1 | .7912 | .9766 | 7.0 | .1275 | .2017 | .20 | .2151 | 11.7798 | .0111 |
| 7 | 2 | .7912 | 1.1312 | 7.0 | .1275 | .2173 | .20 | .2151 | 11.7415 | .0088 |
| 7 | 3 | .7912 | 1.3876 | 7.0 | .1275 | .2275 | .20 | .2151 | 11.8188 | .0207 |
| 7 | 4 | .7912 | 1.6290 | 7.0 | .1275 | .2327 | .20 | .2151 | 12.1503 | .0363 |
| 7 | 5 | .7912 | 1.9193 | 7.0 | .1275 | .2427 | .20 | .2151 | 12.3653 | .0513 |
| 7 | 6 | .7912 | 2.1041 | 7.0 | .1275 | .2581 | .20 | .2151 | 12.3583 | .0518 |
| 8 | 1 | .9091 | .9766 | 7.0 | .1465 | .2017 | .20 | .2151 | 11.6411 | .0022 |
| 8 | 2 | .9091 | 1.1312 | 7.0 | .1465 | .2173 | .20 | .2151 | 11.6064 | .0000 |
| 8 | 3 | .9091 | 1.3876 | 7.0 | .1465 | .2275 | .20 | .2151 | 11.7813 | .0118 |
| 8 | 4 | .9091 | 1.6290 | 7.0 | .1465 | .2327 | .20 | .2151 | 12.0081 | .0274 |
| 8 | 5 | .9091 | 1.9193 | 7.0 | .1465 | .2427 | .20 | .2151 | 12.2198 | .0425 |
| 8 | 6 | .9091 | 2.1041 | 7.0 | .1465 | .2581 | .20 | .2151 | 12.2156 | .0430 |
| 1 | TC | .1973 | .5600 | 7.0 | .0318 | .1229 | .20 | .2151 | 13.6140 | .0985 |
| 2 | TC | .3103 | .5600 | 7.0 | .0500 | .1229 | .20 | .2151 | 13.3848 | .0901 |
| 3 | TC | .3886 | .5600 | 7.0 | .0644 | .1229 | .20 | .2151 | 13.2131 | .0833 |
| 4 | TC | .5184 | .5600 | 7.0 | .0837 | .1229 | .20 | .2151 | 12.9956 | .0744 |
| 5 | TC | .6361 | .5600 | 7.0 | .1025 | .1229 | .20 | .2151 | 12.7964 | .0656 |
| 6 | TC | .7031 | .5600 | 7.0 | .1133 | .1229 | .20 | .2151 | 12.6870 | .0606 |
| 7 | TC | .7912 | .5600 | 7.0 | .1275 | .1229 | .20 | .2151 | 12.5487 | .0540 |

SLACK/RANDOM

MINIMUM SCALING FACTOR= 11.6784

| I | J | AF | AR | WR | MF | MR | D1 | D2 | AJ | ND |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | .1973 | .9766 | 7.0 | .0318 | .2017 | .20 | .2103 | 12.6963 | .0561 |
| 1 | 2 | .1973 | 1.1312 | 7.0 | .0318 | .2173 | .20 | .2103 | 12.6304 | .0537 |
| 1 | 3 | .1973 | 1.3876 | 7.0 | .0318 | .2275 | .20 | .2103 | 12.8209 | .0655 |
| 1 | 4 | .1973 | 1.6290 | 7.0 | .0318 | .2327 | .20 | .2103 | 13.0798 | .0809 |
| 1 | 5 | .1973 | 1.9193 | 7.0 | .0318 | .2427 | .20 | .2103 | 13.3127 | .0858 |
| 1 | 6 | .1973 | 2.1041 | 7.0 | .0318 | .2581 | .20 | .2103 | 13.2839 | .0862 |
| 2 | 1 | .3103 | .9766 | 7.0 | .0500 | .2017 | .20 | .2103 | 12.5179 | .0475 |
| 2 | 2 | .3103 | 1.1312 | 7.0 | .0500 | .2173 | .20 | .2103 | 12.4579 | .0452 |
| 2 | 3 | .3103 | 1.3876 | 7.0 | .0500 | .2275 | .20 | .2103 | 12.6459 | .0569 |
| 2 | 4 | .3103 | 1.6290 | 7.0 | .0500 | .2327 | .20 | .2103 | 12.8994 | .0724 |
| 2 | 5 | .3103 | 1.9193 | 7.0 | .0500 | .2427 | .20 | .2103 | 13.1288 | .0873 |
| 2 | 6 | .3103 | 2.1041 | 7.0 | .0500 | .2581 | .20 | .2103 | 13.1046 | .0877 |
| 3 | 1 | .3996 | .9766 | 7.0 | .0644 | .2017 | .20 | .2103 | 12.3835 | .0408 |
| 3 | 2 | .3996 | 1.1312 | 7.0 | .0644 | .2173 | .20 | .2103 | 12.3277 | .0384 |
| 3 | 3 | .3996 | 1.3876 | 7.0 | .0644 | .2275 | .20 | .2103 | 12.5138 | .0502 |
| 3 | 4 | .3996 | 1.6290 | 7.0 | .0644 | .2327 | .20 | .2103 | 12.7630 | .0657 |
| 3 | 5 | .3996 | 1.9193 | 7.0 | .0644 | .2427 | .20 | .2103 | 12.9896 | .0805 |
| 3 | 6 | .3996 | 2.1041 | 7.0 | .0644 | .2581 | .20 | .2103 | 12.9690 | .0809 |
| 4 | 1 | .5184 | .9766 | 7.0 | .0837 | .2017 | .20 | .2103 | 12.2121 | .0317 |
| 4 | 2 | .5184 | 1.1312 | 7.0 | .0837 | .2173 | .20 | .2103 | 12.1616 | .0294 |
| 4 | 3 | .5184 | 1.3876 | 7.0 | .0837 | .2275 | .20 | .2103 | 12.3451 | .0411 |
| 4 | 4 | .5184 | 1.6290 | 7.0 | .0837 | .2327 | .20 | .2103 | 12.5889 | .0566 |
| 4 | 5 | .5184 | 1.9193 | 7.0 | .0837 | .2427 | .20 | .2103 | 12.8121 | .0715 |
| 4 | 6 | .5184 | 2.1041 | 7.0 | .0837 | .2581 | .20 | .2103 | 12.7855 | .0719 |
| 5 | 1 | .6361 | .9766 | 7.0 | .1025 | .2017 | .20 | .2103 | 12.0541 | .0229 |
| 5 | 2 | .6361 | 1.1312 | 7.0 | .1025 | .2173 | .20 | .2103 | 12.0083 | .0206 |
| 5 | 3 | .6361 | 1.3876 | 7.0 | .1025 | .2275 | .20 | .2103 | 12.1892 | .0323 |
| 5 | 4 | .6361 | 1.6290 | 7.0 | .1025 | .2327 | .20 | .2103 | 12.4280 | .0479 |
| 5 | 5 | .6361 | 1.9193 | 7.0 | .1025 | .2427 | .20 | .2103 | 12.6477 | .0627 |
| 5 | 6 | .6361 | 2.1041 | 7.0 | .1025 | .2581 | .20 | .2103 | 12.3348 | [illegible] |
| 6 | 1 | .7031 | .9766 | 7.0 | .1133 | .2017 | .20 | .2103 | 11.9370 | .0179 |
| 6 | 2 | .7031 | 1.1312 | 7.0 | .1133 | .2173 | .20 | .2103 | 11.9237 | .0155 |
| 6 | 3 | .7031 | 1.3876 | 7.0 | .1133 | .2275 | .20 | .2103 | 12.1031 | .0273 |
| 6 | 4 | .7031 | 1.6290 | 7.0 | .1133 | .2327 | .20 | .2103 | 12.3381 | .0427 |
| 6 | 5 | .7031 | 1.9193 | 7.0 | .1133 | .2427 | .20 | .2103 | 12.5589 | .0576 |
| 6 | 6 | .7031 | 2.1041 | 7.0 | .1133 | .2581 | .20 | .2103 | 12.5459 | .0580 |
| 7 | 1 | .7912 | .9766 | 7.0 | .1275 | .2017 | .20 | .2103 | 11.8563 | .0112 |
| 7 | 2 | .7912 | 1.1312 | 7.0 | .1275 | .2173 | .20 | .2103 | 11.8161 | .0088 |
| 7 | 3 | .7912 | 1.3876 | 7.0 | .1275 | .2275 | .20 | .2103 | 11.9837 | .0206 |
| 7 | 4 | .7912 | 1.6290 | 7.0 | .1275 | .2327 | .20 | .2103 | 12.2260 | .0361 |
| 7 | 5 | .7912 | 1.9193 | 7.0 | .1275 | .2427 | .20 | .2103 | 12.4413 | .0508 |
| 7 | 6 | .7912 | 2.1041 | 7.0 | .1275 | .2581 | .20 | .2103 | 12.4328 | .0514 |
| 8 | 1 | .9091 | .9766 | 7.0 | .1465 | .2017 | .20 | .2103 | 11.7148 | .0023 |
| 8 | 2 | .9091 | 1.1312 | 7.0 | .1465 | .2173 | .20 | .2103 | 11.6784 | .0000 |
| 8 | 3 | .9091 | 1.3876 | 7.0 | .1465 | .2275 | .20 | .2103 | 11.8534 | .0117 |
| 8 | 4 | .9091 | 1.6290 | 7.0 | .1465 | .2327 | .20 | .2103 | 12.0811 | .0272 |
| 8 | 5 | .9091 | 1.9193 | 7.0 | .1465 | .2427 | .20 | .2103 | 12.2931 | .0420 |
| 8 | 6 | .9091 | 2.1041 | 7.0 | .1465 | .2581 | .20 | .2103 | 12.2876 | .0425 |
| 1 | TC | .1973 | .5600 | 7.0 | .0318 | .1229 | .20 | .2103 | 13.7297 | .0932 |
| 2 | TC | .3103 | .5600 | 7.0 | .0500 | .1229 | .20 | .2103 | 13.4950 | .0907 |
| 3 | TC | .3996 | .5600 | 7.0 | .0644 | .1229 | .20 | .2103 | 13.3182 | .0839 |
| 4 | TC | .5184 | .5600 | 7.0 | .0837 | .1229 | .20 | .2103 | 13.0867 | .0749 |
| 5 | TC | .6361 | .5600 | 7.0 | .1025 | .1229 | .20 | .2103 | 12.8830 | .0661 |
| 6 | TC | .7031 | .5600 | 7.0 | .1133 | .1229 | .20 | .2103 | 12.7812 | .0613 |
| 7 | TC | .7912 | .5600 | 7.0 | .1275 | .1229 | .20 | .2103 | 12.6398 | .0543 |

SLACK/FMFS

MINIMUM SCALING FACTOR= 11.7574

| I | J | AF | AR | WE | MF | MR | D1 | D2 | AJ | NO |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | .1973 | .9766 | 7.0 | .0318 | .2017 | .20 | .2051 | 12.7997 | .0566 |
| 1 | 2 | .1973 | 1.1312 | 7.0 | .0318 | .2173 | .20 | .2051 | 12.7308 | .0541 |
| 1 | 3 | .1973 | 1.3876 | 7.0 | .0318 | .2275 | .20 | .2051 | 12.9212 | .0657 |
| 1 | 4 | .1973 | 1.6290 | 7.0 | .0318 | .2327 | .20 | .2051 | 13.1814 | .0811 |
| 1 | 5 | .1973 | 1.9193 | 7.0 | .0318 | .2427 | .20 | .2051 | 13.4146 | .0957 |
| 1 | 6 | .1973 | 2.1041 | 7.0 | .0318 | .2581 | .20 | .2051 | 13.3833 | .0961 |
| 2 | 1 | .3103 | .9766 | 7.0 | .0500 | .2017 | .20 | .2051 | 12.6170 | .0480 |
| 2 | 2 | .3103 | 1.1312 | 7.0 | .0500 | .2173 | .20 | .2051 | 12.5542 | .0455 |
| 2 | 3 | .3103 | 1.3876 | 7.0 | .0500 | .2275 | .20 | .2051 | 12.7423 | .0571 |
| 2 | 4 | .3103 | 1.6290 | 7.0 | .0500 | .2327 | .20 | .2051 | 12.9968 | .0725 |
| 2 | 5 | .3103 | 1.9193 | 7.0 | .0500 | .2427 | .20 | .2051 | 13.2267 | .0872 |
| 2 | 6 | .3103 | 2.1041 | 7.0 | .0500 | .2581 | .20 | .2051 | 13.2002 | .0875 |
| 3 | 1 | .3996 | .9766 | 7.0 | .0644 | .2017 | .20 | .2051 | 12.4794 | .0412 |
| 3 | 2 | .3996 | 1.1312 | 7.0 | .0644 | .2173 | .20 | .2051 | 12.4210 | .0387 |
| 3 | 3 | .3996 | 1.3876 | 7.0 | .0644 | .2275 | .20 | .2051 | 12.6071 | .0503 |
| 3 | 4 | .3996 | 1.6290 | 7.0 | .0644 | .2327 | .20 | .2051 | 12.8575 | .0657 |
| 3 | 5 | .3996 | 1.9193 | 7.0 | .0644 | .2427 | .20 | .2051 | 13.0846 | .0803 |
| 3 | 6 | .3996 | 2.1041 | 7.0 | .0644 | .2581 | .20 | .2051 | 13.0617 | .0807 |
| 4 | 1 | .5194 | .9766 | 7.0 | .0837 | .2017 | .20 | .2051 | 12.3041 | .0321 |
| 4 | 2 | .5194 | 1.1312 | 7.0 | .0837 | .2173 | .20 | .2051 | 12.2512 | .0296 |
| 4 | 3 | .5194 | 1.3876 | 7.0 | .0837 | .2275 | .20 | .2051 | 12.4347 | .0412 |
| 4 | 4 | .5194 | 1.6290 | 7.0 | .0837 | .2327 | .20 | .2051 | 12.6786 | .0565 |
| 4 | 5 | .5194 | 1.9193 | 7.0 | .0837 | .2427 | .20 | .2051 | 12.9032 | .0712 |
| 4 | 6 | .5194 | 2.1041 | 7.0 | .0837 | .2581 | .20 | .2051 | 12.8845 | .0716 |
| 5 | 1 | .6361 | .9766 | 7.0 | .1025 | .2017 | .20 | .2051 | 12.1425 | .0232 |
| 5 | 2 | .6361 | 1.1312 | 7.0 | .1025 | .2173 | .20 | .2051 | 12.0944 | .0207 |
| 5 | 3 | .6361 | 1.3876 | 7.0 | .1025 | .2275 | .20 | .2051 | 12.2754 | .0323 |
| 5 | 4 | .6361 | 1.6290 | 7.0 | .1025 | .2327 | .20 | .2051 | 12.5153 | .0477 |
| 5 | 5 | .6361 | 1.9193 | 7.0 | .1025 | .2427 | .20 | .2051 | 12.7354 | .0624 |
| 5 | 6 | .6361 | 2.1041 | 7.0 | .1025 | .2581 | .20 | .2051 | 12.7206 | .0627 |
| 6 | 1 | .7031 | .9766 | 7.0 | .1133 | .2017 | .20 | .2051 | 12.0534 | .0181 |
| 6 | 2 | .7031 | 1.1312 | 7.0 | .1133 | .2173 | .20 | .2051 | 12.0060 | .0156 |
| 6 | 3 | .7031 | 1.3876 | 7.0 | .1133 | .2275 | .20 | .2051 | 12.1875 | .0272 |
| 6 | 4 | .7031 | 1.6290 | 7.0 | .1133 | .2327 | .20 | .2051 | 12.4245 | .0426 |
| 6 | 5 | .7031 | 1.9193 | 7.0 | .1133 | .2427 | .20 | .2051 | 12.6427 | .0573 |
| 6 | 6 | .7031 | 2.1041 | 7.0 | .1133 | .2581 | .20 | .2051 | 12.6300 | .0576 |
| 7 | 1 | .7912 | .9766 | 7.0 | .1275 | .2017 | .20 | .2051 | 11.9403 | .0114 |
| 7 | 2 | .7912 | 1.1312 | 7.0 | .1275 | .2173 | .20 | .2051 | 11.8981 | .0089 |
| 7 | 3 | .7912 | 1.3876 | 7.0 | .1275 | .2275 | .20 | .2051 | 12.0757 | .0205 |
| 7 | 4 | .7912 | 1.6290 | 7.0 | .1275 | .2327 | .20 | .2051 | 12.3081 | .0359 |
| 7 | 5 | .7912 | 1.9193 | 7.0 | .1275 | .2427 | .20 | .2051 | 12.5248 | .0506 |
| 7 | 6 | .7912 | 2.1041 | 7.0 | .1275 | .2581 | .20 | .2051 | 12.5146 | .0509 |
| 8 | 1 | .9091 | .9766 | 7.0 | .1465 | .2017 | .20 | .2051 | 11.7956 | .0024 |
| 8 | 2 | .9091 | 1.1312 | 7.0 | .1465 | .2173 | .20 | .2051 | 11.7574 | .0000 |
| 8 | 3 | .9091 | 1.3876 | 7.0 | .1465 | .2275 | .20 | .2051 | 11.9326 | .0116 |
| 8 | 4 | .9091 | 1.6290 | 7.0 | .1465 | .2327 | .20 | .2051 | 12.1612 | .0269 |
| 8 | 5 | .9091 | 1.9193 | 7.0 | .1465 | .2427 | .20 | .2051 | 12.3736 | .0416 |
| 8 | 6 | .9091 | 2.1041 | 7.0 | .1465 | .2581 | .20 | .2051 | 12.3665 | .0413 |
| 1 | TC | .1973 | .5600 | 7.0 | .0318 | .1229 | .20 | .2051 | 13.8572 | .0889 |
| 2 | TC | .3103 | .5600 | 7.0 | .0500 | .1229 | .20 | .2051 | 13.6164 | .0913 |
| 3 | TC | .3996 | .5600 | 7.0 | .0644 | .1229 | .20 | .2051 | 13.4361 | .0845 |
| 4 | TC | .5194 | .5600 | 7.0 | .0837 | .1229 | .20 | .2051 | 13.2081 | .0754 |
| 5 | TC | .6361 | .5600 | 7.0 | .1025 | .1229 | .20 | .2051 | 12.9893 | .0666 |
| 6 | TC | .7031 | .5600 | 7.0 | .1133 | .1229 | .20 | .2051 | 12.8848 | .0614 |
| 7 | TC | .7912 | .5600 | 7.0 | .1275 | .1229 | .20 | .2051 | 12.7401 | .0547 |

SLACK/NINO

MINIMUM SCALING FACTOR= 11.599

| I | J | AF | AR | WE | MF | MR | D1 | D2 | AJ | ND |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | .1973 | .8766 | 7.0 | .0318 | .2017 | .20 | .2156 | 12.5926 | .0556 |
| 1 | 2 | .1973 | 1.1312 | 7.0 | .0318 | .2173 | .20 | .2156 | 12.5297 | .0533 |
| 1 | 3 | .1973 | 1.3876 | 7.0 | .0318 | .2275 | .20 | .2156 | 12.7202 | .0652 |
| 1 | 4 | .1973 | 1.6290 | 7.0 | .0318 | .2327 | .20 | .2156 | 12.9779 | .0808 |
| 1 | 5 | .1973 | 1.9183 | 7.0 | .0318 | .2427 | .20 | .2156 | 13.2105 | .0958 |
| 1 | 6 | .1973 | 2.1041 | 7.0 | .0318 | .2581 | .20 | .2156 | 13.1841 | .0984 |
| 2 | 1 | .3103 | .8766 | 7.0 | .0500 | .2017 | .20 | .2156 | 12.4185 | .0471 |
| 2 | 2 | .3103 | 1.1312 | 7.0 | .0500 | .2173 | .20 | .2156 | 12.3612 | .0448 |
| 2 | 3 | .3103 | 1.3876 | 7.0 | .0500 | .2275 | .20 | .2156 | 12.5492 | .0587 |
| 2 | 4 | .3103 | 1.6290 | 7.0 | .0500 | .2327 | .20 | .2156 | 12.8015 | .0723 |
| 2 | 5 | .3103 | 1.9183 | 7.0 | .0500 | .2427 | .20 | .2156 | 13.0306 | .0874 |
| 2 | 6 | .3103 | 2.1041 | 7.0 | .0500 | .2581 | .20 | .2156 | 13.0067 | .0879 |
| 3 | 1 | .3996 | .8766 | 7.0 | .0644 | .2017 | .20 | .2156 | 12.2872 | .0404 |
| 3 | 2 | .3996 | 1.1312 | 7.0 | .0644 | .2173 | .20 | .2156 | 12.2340 | .0381 |
| 3 | 3 | .3996 | 1.3876 | 7.0 | .0644 | .2275 | .20 | .2156 | 12.4200 | .0500 |
| 3 | 4 | .3996 | 1.6290 | 7.0 | .0644 | .2327 | .20 | .2156 | 12.6681 | .0656 |
| 3 | 5 | .3996 | 1.9183 | 7.0 | .0644 | .2427 | .20 | .2156 | 12.8945 | .0807 |
| 3 | 6 | .3996 | 2.1041 | 7.0 | .0644 | .2581 | .20 | .2156 | 12.8758 | .0812 |
| 4 | 1 | .5194 | .8766 | 7.0 | .0837 | .2017 | .20 | .2156 | 12.1186 | .0314 |
| 4 | 2 | .5194 | 1.1312 | 7.0 | .0837 | .2173 | .20 | .2156 | 12.0717 | .0292 |
| 4 | 3 | .5194 | 1.3876 | 7.0 | .0837 | .2275 | .20 | .2156 | 12.2550 | .0411 |
| 4 | 4 | .5194 | 1.6290 | 7.0 | .0837 | .2327 | .20 | .2156 | 12.4978 | .0567 |
| 4 | 5 | .5194 | 1.9183 | 7.0 | .0837 | .2427 | .20 | .2156 | 12.7206 | .0717 |
| 4 | 6 | .5194 | 2.1041 | 7.0 | .0837 | .2581 | .20 | .2156 | 12.7059 | .0722 |
| 5 | 1 | .6361 | .8766 | 7.0 | .1025 | .2017 | .20 | .2156 | 11.9654 | .0227 |
| 5 | 2 | .6361 | 1.1312 | 7.0 | .1025 | .2173 | .20 | .2156 | 11.9218 | .0204 |
| 5 | 3 | .6361 | 1.3876 | 7.0 | .1025 | .2275 | .20 | .2156 | 12.1026 | .0323 |
| 5 | 4 | .6361 | 1.6290 | 7.0 | .1025 | .2327 | .20 | .2156 | 12.3403 | .0479 |
| 5 | 5 | .6361 | 1.9183 | 7.0 | .1025 | .2427 | .20 | .2156 | 12.5596 | .0630 |
| 5 | 6 | .6361 | 2.1041 | 7.0 | .1025 | .2581 | .20 | .2156 | 12.5485 | .0635 |
| 6 | 1 | .7031 | .8766 | 7.0 | .1133 | .2017 | .20 | .2156 | 11.8802 | .0177 |
| 6 | 2 | .7031 | 1.1312 | 7.0 | .1133 | .2173 | .20 | .2156 | 11.8380 | .0154 |
| 6 | 3 | .7031 | 1.3876 | 7.0 | .1133 | .2275 | .20 | .2156 | 12.0183 | .0273 |
| 6 | 4 | .7031 | 1.6290 | 7.0 | .1133 | .2327 | .20 | .2156 | 12.2532 | .0429 |
| 6 | 5 | .7031 | 1.9183 | 7.0 | .1133 | .2427 | .20 | .2156 | 12.4707 | .0579 |
| 6 | 6 | .7031 | 2.1041 | 7.0 | .1133 | .2581 | .20 | .2156 | 12.4614 | .0585 |
| 7 | 1 | .7912 | .8766 | 7.0 | .1275 | .2017 | .20 | .2156 | 11.7720 | .0111 |
| 7 | 2 | .7912 | 1.1312 | 7.0 | .1275 | .2173 | .20 | .2156 | 11.7338 | .0088 |
| 7 | 3 | .7912 | 1.3876 | 7.0 | .1275 | .2275 | .20 | .2156 | 11.9112 | .0207 |
| 7 | 4 | .7912 | 1.6290 | 7.0 | .1275 | .2327 | .20 | .2156 | 12.1425 | .0363 |
| 7 | 5 | .7912 | 1.9183 | 7.0 | .1275 | .2427 | .20 | .2156 | 12.3574 | .0513 |
| 7 | 6 | .7912 | 2.1041 | 7.0 | .1275 | .2581 | .20 | .2156 | 12.3505 | .0513 |
| 8 | 1 | .9081 | .8766 | 7.0 | .1465 | .2017 | .20 | .2156 | 11.6335 | .0022 |
| 8 | 2 | .9081 | 1.1312 | 7.0 | .1465 | .2173 | .20 | .2156 | 11.5990 | .0000 |
| 8 | 3 | .9081 | 1.3876 | 7.0 | .1465 | .2275 | .20 | .2156 | 11.7739 | .0119 |
| 8 | 4 | .9081 | 1.6290 | 7.0 | .1465 | .2327 | .20 | .2156 | 12.0006 | .0275 |
| 8 | 5 | .9081 | 1.9183 | 7.0 | .1465 | .2427 | .20 | .2156 | 12.2122 | .0425 |
| 8 | 6 | .9081 | 2.1041 | 7.0 | .1465 | .2581 | .20 | .2156 | 12.2082 | .0430 |
| 1 | TC | .1873 | .5600 | 7.0 | .0318 | .1229 | .20 | .2156 | 13.6021 | .0984 |
| 2 | TC | .3103 | .5600 | 7.0 | .0500 | .1229 | .20 | .2156 | 13.3734 | .0900 |
| 3 | TC | .3996 | .5600 | 7.0 | .0644 | .1229 | .20 | .2156 | 13.2021 | .0833 |
| 4 | TC | .5194 | .5600 | 7.0 | .0837 | .1229 | .20 | .2156 | 12.9852 | .0743 |
| 5 | TC | .6361 | .5600 | 7.0 | .1025 | .1229 | .20 | .2156 | 12.7864 | .0656 |
| 6 | TC | .7031 | .5600 | 7.0 | .1133 | .1229 | .20 | .2156 | 12.6773 | .0605 |
| 7 | TC | .7912 | .5600 | 7.0 | .1275 | .1229 | .20 | .2156 | 12.5393 | .0533 |

SLACK/WING

MINIMUM SCALING FACTOR= 11.6528

| I | J | AF | AR | WR | MF | MR | D1 | D2 | AJ | ND |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | .1873 | .9766 | 7.0 | .0318 | .2017 | .20 | .2120 | 12.6628 | .0559 |
| 1 | 2 | .1873 | 1.1312 | 7.0 | .0318 | .2173 | .20 | .2120 | 12.5979 | .0536 |
| 1 | 3 | .1873 | 1.3876 | 7.0 | .0318 | .2275 | .20 | .2120 | 12.7884 | .0654 |
| 1 | 4 | .1873 | 1.6290 | 7.0 | .0318 | .2327 | .20 | .2120 | 13.0470 | .0809 |
| 1 | 5 | .1873 | 1.9193 | 7.0 | .0318 | .2427 | .20 | .2120 | 13.2798 | .0858 |
| 1 | 6 | .1873 | 2.1041 | 7.0 | .0318 | .2581 | .20 | .2120 | 13.2517 | .0863 |
| 2 | 1 | .3103 | .9766 | 7.0 | .0500 | .2017 | .20 | .2120 | 12.4859 | .0474 |
| 2 | 2 | .3103 | 1.1312 | 7.0 | .0500 | .2173 | .20 | .2120 | 12.4267 | .0451 |
| 2 | 3 | .3103 | 1.3876 | 7.0 | .0500 | .2275 | .20 | .2120 | 12.6147 | .0569 |
| 2 | 4 | .3103 | 1.6290 | 7.0 | .0500 | .2327 | .20 | .2120 | 12.8676 | .0724 |
| 2 | 5 | .3103 | 1.9193 | 7.0 | .0500 | .2427 | .20 | .2120 | 13.0872 | .0873 |
| 2 | 6 | .3103 | 2.1041 | 7.0 | .0500 | .2581 | .20 | .2120 | 13.0737 | .0878 |
| 3 | 1 | .3886 | .9766 | 7.0 | .0644 | .2017 | .20 | .2120 | 12.3524 | .0407 |
| 3 | 2 | .3886 | 1.1312 | 7.0 | .0644 | .2173 | .20 | .2120 | 12.2975 | .0383 |
| 3 | 3 | .3886 | 1.3876 | 7.0 | .0644 | .2275 | .20 | .2120 | 12.4835 | .0501 |
| 3 | 4 | .3886 | 1.6290 | 7.0 | .0644 | .2327 | .20 | .2120 | 12.7324 | .0657 |
| 3 | 5 | .3886 | 1.9193 | 7.0 | .0644 | .2427 | .20 | .2120 | 12.9591 | .0806 |
| 3 | 6 | .3886 | 2.1041 | 7.0 | .0644 | .2581 | .20 | .2120 | 12.9390 | .0810 |
| 4 | 1 | .5184 | .9766 | 7.0 | .0837 | .2017 | .20 | .2120 | 12.1823 | .0316 |
| 4 | 2 | .5184 | 1.1312 | 7.0 | .0837 | .2173 | .20 | .2120 | 12.1326 | .0293 |
| 4 | 3 | .5184 | 1.3876 | 7.0 | .0837 | .2275 | .20 | .2120 | 12.3160 | .0411 |
| 4 | 4 | .5184 | 1.6290 | 7.0 | .0837 | .2327 | .20 | .2120 | 12.5585 | .0566 |
| 4 | 5 | .5184 | 1.9193 | 7.0 | .0837 | .2427 | .20 | .2120 | 12.7826 | .0715 |
| 4 | 6 | .5184 | 2.1041 | 7.0 | .0837 | .2581 | .20 | .2120 | 12.7666 | .0720 |
| 5 | 1 | .6361 | .9766 | 7.0 | .1025 | .2017 | .20 | .2120 | 12.0255 | .0229 |
| 5 | 2 | .6361 | 1.1312 | 7.0 | .1025 | .2173 | .20 | .2120 | 11.9804 | .0205 |
| 5 | 3 | .6361 | 1.3876 | 7.0 | .1025 | .2275 | .20 | .2120 | 12.1613 | .0323 |
| 5 | 4 | .6361 | 1.6290 | 7.0 | .1025 | .2327 | .20 | .2120 | 12.3987 | .0478 |
| 5 | 5 | .6361 | 1.9193 | 7.0 | .1025 | .2427 | .20 | .2120 | 12.6193 | .0628 |
| 5 | 6 | .6361 | 2.1041 | 7.0 | .1025 | .2581 | .20 | .2120 | 12.6070 | .0632 |
| 6 | 1 | .7031 | .9766 | 7.0 | .1133 | .2017 | .20 | .2120 | 11.9390 | .0178 |
| 6 | 2 | .7031 | 1.1312 | 7.0 | .1133 | .2173 | .20 | .2120 | 11.8864 | .0155 |
| 6 | 3 | .7031 | 1.3876 | 7.0 | .1133 | .2275 | .20 | .2120 | 12.0758 | .0273 |
| 6 | 4 | .7031 | 1.6290 | 7.0 | .1133 | .2327 | .20 | .2120 | 12.3114 | .0428 |
| 6 | 5 | .7031 | 1.9193 | 7.0 | .1133 | .2427 | .20 | .2120 | 12.5281 | .0577 |
| 6 | 6 | .7031 | 2.1041 | 7.0 | .1133 | .2581 | .20 | .2120 | 12.5187 | .0582 |
| 7 | 1 | .7912 | .9766 | 7.0 | .1275 | .2017 | .20 | .2120 | 11.8281 | .0112 |
| 7 | 2 | .7912 | 1.1312 | 7.0 | .1275 | .2173 | .20 | .2120 | 11.7886 | .0088 |
| 7 | 3 | .7912 | 1.3876 | 7.0 | .1275 | .2275 | .20 | .2120 | 11.9671 | .0206 |
| 7 | 4 | .7912 | 1.6290 | 7.0 | .1275 | .2327 | .20 | .2120 | 12.1981 | .0362 |
| 7 | 5 | .7912 | 1.9193 | 7.0 | .1275 | .2427 | .20 | .2120 | 12.4143 | .0511 |
| 7 | 6 | .7912 | 2.1041 | 7.0 | .1275 | .2581 | .20 | .2120 | 12.4063 | .0515 |
| 8 | 1 | .8091 | .9766 | 7.0 | .1465 | .2017 | .20 | .2120 | 11.6886 | .0023 |
| 8 | 2 | .8091 | 1.1312 | 7.0 | .1465 | .2173 | .20 | .2120 | 11.6528 | .0000 |
| 8 | 3 | .8091 | 1.3876 | 7.0 | .1465 | .2275 | .20 | .2120 | 11.8278 | .0118 |
| 8 | 4 | .8091 | 1.6290 | 7.0 | .1465 | .2327 | .20 | .2120 | 12.0552 | .0273 |
| 8 | 5 | .8091 | 1.9193 | 7.0 | .1465 | .2427 | .20 | .2120 | 12.2670 | .0422 |
| 8 | 6 | .8091 | 2.1041 | 7.0 | .1465 | .2581 | .20 | .2120 | 12.2620 | .0426 |
| 1 | TC | .1873 | .5600 | 7.0 | .0318 | .1229 | .20 | .2120 | 13.6885 | .0990 |
| 2 | TC | .3103 | .5600 | 7.0 | .0500 | .1229 | .20 | .2120 | 13.4558 | .0904 |
| 3 | TC | .3886 | .5600 | 7.0 | .0644 | .1229 | .20 | .2120 | 13.2814 | .0837 |
| 4 | TC | .5184 | .5600 | 7.0 | .0837 | .1229 | .20 | .2120 | 13.0607 | .0747 |
| 5 | TC | .6361 | .5600 | 7.0 | .1025 | .1229 | .20 | .2120 | 12.8586 | .0659 |
| 6 | TC | .7031 | .5600 | 7.0 | .1133 | .1229 | .20 | .2120 | 12.7477 | .0609 |
| 7 | TC | .7912 | .5600 | 7.0 | .1275 | .1229 | .20 | .2120 | 12.6074 | .0542 |

S/PT/RANDOM

MINIMUM SCALING FACTOR= 11.7927

| I | J | AF | AR | WR | MF | MR | D1 | D2 | AJ | ND |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | .1973 | .9766 | 7.0 | .0318 | .2017 | .20 | .2028 | 12.8459 | .0566 |
| 1 | 2 | .1973 | 1.1312 | 7.0 | .0318 | .2173 | .20 | .2028 | 12.7757 | .0543 |
| 1 | 3 | .1973 | 1.3876 | 7.0 | .0318 | .2275 | .20 | .2028 | 12.9661 | .0658 |
| 1 | 4 | .1973 | 1.6290 | 7.0 | .0318 | .2327 | .20 | .2028 | 13.2288 | .0811 |
| 1 | 5 | .1973 | 1.9193 | 7.0 | .0318 | .2427 | .20 | .2028 | 13.4602 | .0957 |
| 1 | 6 | .1973 | 2.1041 | 7.0 | .0318 | .2581 | .20 | .2028 | 13.4877 | .0960 |
| 2 | 1 | .3103 | .9766 | 7.0 | .0500 | .2017 | .20 | .2028 | 12.6614 | .0492 |
| 2 | 2 | .3103 | 1.1312 | 7.0 | .0500 | .2173 | .20 | .2028 | 12.5973 | .0487 |
| 2 | 3 | .3103 | 1.3876 | 7.0 | .0500 | .2275 | .20 | .2028 | 12.7853 | .0572 |
| 2 | 4 | .3103 | 1.6290 | 7.0 | .0500 | .2327 | .20 | .2028 | 13.0405 | .0725 |
| 2 | 5 | .3103 | 1.9193 | 7.0 | .0500 | .2427 | .20 | .2028 | 13.2704 | .0871 |
| 2 | 6 | .3103 | 2.1041 | 7.0 | .0500 | .2581 | .20 | .2028 | 13.2429 | .0874 |
| 3 | 1 | .3996 | .9766 | 7.0 | .0644 | .2017 | .20 | .2028 | 12.5223 | .0413 |
| 3 | 2 | .3996 | 1.1312 | 7.0 | .0644 | .2173 | .20 | .2028 | 12.4628 | .0388 |
| 3 | 3 | .3996 | 1.3876 | 7.0 | .0644 | .2275 | .20 | .2028 | 12.6469 | .0504 |
| 3 | 4 | .3996 | 1.6290 | 7.0 | .0644 | .2327 | .20 | .2028 | 12.8988 | .0657 |
| 3 | 5 | .3996 | 1.9193 | 7.0 | .0644 | .2427 | .20 | .2028 | 13.1270 | .0803 |
| 3 | 6 | .3996 | 2.1041 | 7.0 | .0644 | .2581 | .20 | .2028 | 13.1031 | .0805 |
| 4 | 1 | .5194 | .9766 | 7.0 | .0837 | .2017 | .20 | .2028 | 12.3452 | .0322 |
| 4 | 2 | .5194 | 1.1312 | 7.0 | .0837 | .2173 | .20 | .2028 | 12.2812 | .0297 |
| 4 | 3 | .5194 | 1.3876 | 7.0 | .0837 | .2275 | .20 | .2028 | 12.4747 | .0412 |
| 4 | 4 | .5194 | 1.6290 | 7.0 | .0837 | .2327 | .20 | .2028 | 12.7202 | .0565 |
| 4 | 5 | .5194 | 1.9193 | 7.0 | .0837 | .2427 | .20 | .2028 | 12.9439 | .0711 |
| 4 | 6 | .5194 | 2.1041 | 7.0 | .0837 | .2581 | .20 | .2028 | 12.9243 | .0714 |
| 5 | 1 | .6361 | .9766 | 7.0 | .1025 | .2017 | .20 | .2028 | 12.1920 | .0233 |
| 5 | 2 | .6361 | 1.1312 | 7.0 | .1025 | .2173 | .20 | .2028 | 12.1329 | .0208 |
| 5 | 3 | .6361 | 1.3876 | 7.0 | .1025 | .2275 | .20 | .2028 | 12.3140 | .0323 |
| 5 | 4 | .6361 | 1.6290 | 7.0 | .1025 | .2327 | .20 | .2028 | 12.5543 | .0476 |
| 5 | 5 | .6361 | 1.9193 | 7.0 | .1025 | .2427 | .20 | .2028 | 12.7745 | .0622 |
| 5 | 6 | .6361 | 2.1041 | 7.0 | .1025 | .2581 | .20 | .2028 | 12.7589 | .0625 |
| 6 | 1 | .7031 | .9766 | 7.0 | .1133 | .2017 | .20 | .2028 | 12.0920 | .0182 |
| 6 | 2 | .7031 | 1.1312 | 7.0 | .1133 | .2173 | .20 | .2028 | 12.0456 | .0157 |
| 6 | 3 | .7031 | 1.3876 | 7.0 | .1133 | .2275 | .20 | .2028 | 12.2252 | .0272 |
| 6 | 4 | .7031 | 1.6290 | 7.0 | .1133 | .2327 | .20 | .2028 | 12.4627 | .0425 |
| 6 | 5 | .7031 | 1.9193 | 7.0 | .1133 | .2427 | .20 | .2028 | 12.6810 | .0571 |
| 6 | 6 | .7031 | 2.1041 | 7.0 | .1133 | .2581 | .20 | .2028 | 12.6875 | .0574 |
| 7 | 1 | .7912 | .9766 | 7.0 | .1275 | .2017 | .20 | .2028 | 11.9778 | .0114 |
| 7 | 2 | .7912 | 1.1312 | 7.0 | .1275 | .2173 | .20 | .2028 | 11.9347 | .0090 |
| 7 | 3 | .7912 | 1.3876 | 7.0 | .1275 | .2275 | .20 | .2028 | 12.1124 | .0205 |
| 7 | 4 | .7912 | 1.6290 | 7.0 | .1275 | .2327 | .20 | .2028 | 12.3462 | .0358 |
| 7 | 5 | .7912 | 1.9193 | 7.0 | .1275 | .2427 | .20 | .2028 | 12.5620 | .0504 |
| 7 | 6 | .7912 | 2.1041 | 7.0 | .1275 | .2581 | .20 | .2028 | 12.5511 | .0507 |
| 8 | 1 | .9081 | .9766 | 7.0 | .1465 | .2017 | .20 | .2028 | 11.8318 | .0024 |
| 8 | 2 | .9081 | 1.1312 | 7.0 | .1465 | .2173 | .20 | .2028 | 11.7927 | .0000 |
| 8 | 3 | .9081 | 1.3876 | 7.0 | .1465 | .2275 | .20 | .2028 | 11.9679 | .0115 |
| 8 | 4 | .9081 | 1.6290 | 7.0 | .1465 | .2327 | .20 | .2028 | 12.1970 | .0268 |
| 8 | 5 | .9081 | 1.9193 | 7.0 | .1465 | .2427 | .20 | .2028 | 12.4095 | .0414 |
| 8 | 6 | .9081 | 2.1041 | 7.0 | .1465 | .2581 | .20 | .2028 | 12.4017 | .0417 |
| 1 | TC | .1973 | .5600 | 7.0 | .0318 | .1229 | .20 | .2028 | 13.9144 | .1003 |
| 2 | TC | .3103 | .5600 | 7.0 | .0500 | .1229 | .20 | .2028 | 13.6708 | .0916 |
| 3 | TC | .3996 | .5600 | 7.0 | .0644 | .1229 | .20 | .2028 | 13.4885 | .0848 |
| 4 | TC | .5194 | .5600 | 7.0 | .0837 | .1229 | .20 | .2028 | 13.2579 | .0757 |
| 5 | TC | .6361 | .5600 | 7.0 | .1025 | .1229 | .20 | .2028 | 13.0469 | .0663 |
| 6 | TC | .7031 | .5600 | 7.0 | .1133 | .1229 | .20 | .2028 | 12.9312 | .0616 |
| 7 | TC | .7912 | .5600 | 7.0 | .1275 | .1229 | .20 | .2028 | 12.7850 | .0549 |

S/PT/FMFS

MINIMUM SCALING FACTOR= 11.9217

| I | J | AF | AR | W2 | MF | MR | D1 | D2 | AJ | ND |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | .1973 | .9766 | 7.0 | .0318 | .2017 | .20 | .1845 | 13.0157 | .0576 |
| 1 | 2 | .1973 | 1.1312 | 7.0 | .0318 | .2173 | .20 | .1845 | 12.9404 | .0550 |
| 1 | 3 | .1973 | 1.3876 | 7.0 | .0318 | .2275 | .20 | .1845 | 13.1307 | .0663 |
| 1 | 4 | .1973 | 1.6290 | 7.0 | .0318 | .2327 | .20 | .1845 | 13.3934 | .0813 |
| 1 | 5 | .1973 | 1.9193 | 7.0 | .0318 | .2427 | .20 | .1845 | 13.6272 | .0957 |
| 1 | 6 | .1973 | 2.1041 | 7.0 | .0318 | .2581 | .20 | .1845 | 13.5805 | .0958 |
| 2 | 1 | .3103 | .9766 | 7.0 | .0500 | .2017 | .20 | .1845 | 12.8240 | .0489 |
| 2 | 2 | .3103 | 1.1312 | 7.0 | .0500 | .2173 | .20 | .1845 | 12.7553 | .0462 |
| 2 | 3 | .3103 | 1.3876 | 7.0 | .0500 | .2275 | .20 | .1845 | 12.9433 | .0575 |
| 2 | 4 | .3103 | 1.6290 | 7.0 | .0500 | .2327 | .20 | .1845 | 13.2003 | .0726 |
| 2 | 5 | .3103 | 1.9193 | 7.0 | .0500 | .2427 | .20 | .1845 | 13.4307 | .0869 |
| 2 | 6 | .3103 | 2.1041 | 7.0 | .0500 | .2581 | .20 | .1845 | 13.3993 | .0870 |
| 3 | 1 | .3886 | .9766 | 7.0 | .0644 | .2017 | .20 | .1845 | 12.6796 | .0420 |
| 3 | 2 | .3886 | 1.1312 | 7.0 | .0644 | .2173 | .20 | .1845 | 12.6157 | .0393 |
| 3 | 3 | .3886 | 1.3876 | 7.0 | .0644 | .2275 | .20 | .1845 | 12.8018 | .0506 |
| 3 | 4 | .3886 | 1.6290 | 7.0 | .0644 | .2327 | .20 | .1845 | 13.0546 | .0657 |
| 3 | 5 | .3886 | 1.9193 | 7.0 | .0644 | .2427 | .20 | .1845 | 13.2823 | .0800 |
| 3 | 6 | .3886 | 2.1041 | 7.0 | .0644 | .2581 | .20 | .1845 | 13.2548 | .0801 |
| 4 | 1 | .5194 | .9766 | 7.0 | .0837 | .2017 | .20 | .1845 | 12.4859 | .0327 |
| 4 | 2 | .5194 | 1.1312 | 7.0 | .0837 | .2173 | .20 | .1845 | 12.4379 | .0301 |
| 4 | 3 | .5194 | 1.3876 | 7.0 | .0837 | .2275 | .20 | .1845 | 12.6215 | .0414 |
| 4 | 4 | .5194 | 1.6290 | 7.0 | .0837 | .2327 | .20 | .1845 | 12.8687 | .0564 |
| 4 | 5 | .5194 | 1.9193 | 7.0 | .0837 | .2427 | .20 | .1845 | 13.0088 | .0706 |
| 4 | 6 | .5194 | 2.1041 | 7.0 | .0837 | .2581 | .20 | .1845 | 13.0700 | .0709 |
| 5 | 1 | .6361 | .9766 | 7.0 | .1025 | .2017 | .20 | .1845 | 12.3267 | .0237 |
| 5 | 2 | .6361 | 1.1312 | 7.0 | .1025 | .2173 | .20 | .1845 | 12.2739 | .0211 |
| 5 | 3 | .6361 | 1.3876 | 7.0 | .1025 | .2275 | .20 | .1845 | 12.4550 | .0324 |
| 5 | 4 | .6361 | 1.6290 | 7.0 | .1025 | .2327 | .20 | .1845 | 12.6871 | .0474 |
| 5 | 5 | .6361 | 1.9193 | 7.0 | .1025 | .2427 | .20 | .1845 | 12.9179 | .0618 |
| 5 | 6 | .6361 | 2.1041 | 7.0 | .1025 | .2581 | .20 | .1845 | 12.8882 | .0613 |
| 6 | 1 | .7031 | .9766 | 7.0 | .1133 | .2017 | .20 | .1845 | 12.2335 | .0185 |
| 6 | 2 | .7031 | 1.1312 | 7.0 | .1133 | .2173 | .20 | .1845 | 12.1835 | .0159 |
| 6 | 3 | .7031 | 1.3876 | 7.0 | .1133 | .2275 | .20 | .1845 | 12.3632 | .0272 |
| 6 | 4 | .7031 | 1.6290 | 7.0 | .1133 | .2327 | .20 | .1845 | 12.6024 | .0422 |
| 6 | 5 | .7031 | 1.9193 | 7.0 | .1133 | .2427 | .20 | .1845 | 12.8213 | .0566 |
| 6 | 6 | .7031 | 2.1041 | 7.0 | .1133 | .2581 | .20 | .1845 | 12.8048 | .0567 |
| 7 | 1 | .7912 | .9766 | 7.0 | .1275 | .2017 | .20 | .1845 | 12.1152 | .0117 |
| 7 | 2 | .7912 | 1.1312 | 7.0 | .1275 | .2173 | .20 | .1845 | 12.0687 | .0091 |
| 7 | 3 | .7912 | 1.3876 | 7.0 | .1275 | .2275 | .20 | .1845 | 12.2465 | .0204 |
| 7 | 4 | .7912 | 1.6290 | 7.0 | .1275 | .2327 | .20 | .1845 | 12.4820 | .0354 |
| 7 | 5 | .7912 | 1.9193 | 7.0 | .1275 | .2427 | .20 | .1845 | 12.6884 | .0458 |
| 7 | 6 | .7912 | 2.1041 | 7.0 | .1275 | .2581 | .20 | .1845 | 12.6846 | .0405 |
| 8 | 1 | .9091 | .9766 | 7.0 | .1465 | .2017 | .20 | .1845 | 11.9640 | .0026 |
| 8 | 2 | .9091 | 1.1312 | 7.0 | .1465 | .2173 | .20 | .1845 | 11.9217 | .0000 |
| 8 | 3 | .9091 | 1.3876 | 7.0 | .1465 | .2275 | .20 | .1845 | 12.0372 | .0113 |
| 8 | 4 | .9091 | 1.6290 | 7.0 | .1465 | .2327 | .20 | .1845 | 12.3279 | .0263 |
| 8 | 5 | .9091 | 1.9193 | 7.0 | .1465 | .2427 | .20 | .1845 | 12.5410 | .0407 |
| 8 | 6 | .9091 | 2.1041 | 7.0 | .1465 | .2581 | .20 | .1845 | 12.5305 | .0408 |
| 1 | TC | .1973 | .5600 | 7.0 | .0318 | .1229 | .20 | .1845 | 14.1247 | .1014 |
| 2 | TC | .3103 | .5600 | 7.0 | .0500 | .1229 | .20 | .1845 | 13.8768 | .0927 |
| 3 | TC | .3886 | .5600 | 7.0 | .0644 | .1229 | .20 | .1845 | 13.6809 | .0858 |
| 4 | TC | .5194 | .5600 | 7.0 | .0837 | .1229 | .20 | .1845 | 13.4410 | .0766 |
| 5 | TC | .6361 | .5600 | 7.0 | .1025 | .1229 | .20 | .1845 | 13.2216 | .0675 |
| 6 | TC | .7031 | .5600 | 7.0 | .1133 | .1229 | .20 | .1845 | 13.1014 | .0624 |
| 7 | TC | .7912 | .5600 | 7.0 | .1275 | .1229 | .20 | .1845 | 12.9496 | .0556 |

S/PT/NINQ

MINIMUM SCALING FACTOR= 11.8739

| I | J | AF | AR | W2 | MF | MR | D1 | D2 | AJ | ND |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | .1973 | .9766 | 7.0 | .0318 | .2017 | .20 | .2106 | 12.6904 | .0560 |
| 1 | 2 | .1973 | 1.1312 | 7.0 | .0318 | .2173 | .20 | .2106 | 12.6246 | .0537 |
| 1 | 3 | .1973 | 1.3876 | 7.0 | .0318 | .2275 | .20 | .2106 | 12.8151 | .0654 |
| 1 | 4 | .1973 | 1.6290 | 7.0 | .0318 | .2327 | .20 | .2106 | 13.0740 | .0809 |
| 1 | 5 | .1973 | 1.9193 | 7.0 | .0318 | .2427 | .20 | .2106 | 13.3069 | .0958 |
| 1 | 6 | .1973 | 2.1041 | 7.0 | .0318 | .2581 | .20 | .2106 | 13.2782 | .0962 |
| 2 | 1 | .3103 | .9766 | 7.0 | .0500 | .2017 | .20 | .2106 | 12.5123 | .0475 |
| 2 | 2 | .3103 | 1.1312 | 7.0 | .0500 | .2173 | .20 | .2106 | 12.4524 | .0452 |
| 2 | 3 | .3103 | 1.3876 | 7.0 | .0500 | .2275 | .20 | .2106 | 12.6404 | .0563 |
| 2 | 4 | .3103 | 1.6290 | 7.0 | .0500 | .2327 | .20 | .2106 | 12.8938 | .0724 |
| 2 | 5 | .3103 | 1.9193 | 7.0 | .0500 | .2427 | .20 | .2106 | 13.1232 | .0873 |
| 2 | 6 | .3103 | 2.1041 | 7.0 | .0500 | .2581 | .20 | .2106 | 13.0892 | .0877 |
| 3 | 1 | .3886 | .9766 | 7.0 | .0644 | .2017 | .20 | .2106 | 12.3780 | .0408 |
| 3 | 2 | .3886 | 1.1312 | 7.0 | .0644 | .2173 | .20 | .2106 | 12.3224 | .0384 |
| 3 | 3 | .3886 | 1.3876 | 7.0 | .0644 | .2275 | .20 | .2106 | 12.5084 | .0502 |
| 3 | 4 | .3886 | 1.6290 | 7.0 | .0644 | .2327 | .20 | .2106 | 12.7576 | .0657 |
| 3 | 5 | .3886 | 1.9193 | 7.0 | .0644 | .2427 | .20 | .2106 | 12.9843 | .0805 |
| 3 | 6 | .3886 | 2.1041 | 7.0 | .0644 | .2581 | .20 | .2106 | 12.9637 | .0809 |
| 4 | 1 | .5194 | .9766 | 7.0 | .0837 | .2017 | .20 | .2106 | 12.2068 | .0317 |
| 4 | 2 | .5194 | 1.1312 | 7.0 | .0837 | .2173 | .20 | .2106 | 12.1565 | .0294 |
| 4 | 3 | .5194 | 1.3876 | 7.0 | .0837 | .2275 | .20 | .2106 | 12.3398 | .0411 |
| 4 | 4 | .5194 | 1.6290 | 7.0 | .0837 | .2327 | .20 | .2106 | 12.5837 | .0566 |
| 4 | 5 | .5194 | 1.9193 | 7.0 | .0837 | .2427 | .20 | .2106 | 12.8069 | .0715 |
| 4 | 6 | .5194 | 2.1041 | 7.0 | .0837 | .2581 | .20 | .2106 | 12.7904 | .0719 |
| 5 | 1 | .6361 | .9766 | 7.0 | .1025 | .2017 | .20 | .2106 | 12.0491 | .0223 |
| 5 | 2 | .6361 | 1.1312 | 7.0 | .1025 | .2173 | .20 | .2106 | 12.0034 | .0208 |
| 5 | 3 | .6361 | 1.3876 | 7.0 | .1025 | .2275 | .20 | .2106 | 12.1843 | .0323 |
| 5 | 4 | .6361 | 1.6290 | 7.0 | .1025 | .2327 | .20 | .2106 | 12.4230 | .0478 |
| 5 | 5 | .6361 | 1.9193 | 7.0 | .1025 | .2427 | .20 | .2106 | 12.6427 | .0627 |
| 5 | 6 | .6361 | 2.1041 | 7.0 | .1025 | .2581 | .20 | .2106 | 12.6298 | .0631 |
| 6 | 1 | .7031 | .9766 | 7.0 | .1133 | .2017 | .20 | .2106 | 11.9621 | .0178 |
| 6 | 2 | .7031 | 1.1312 | 7.0 | .1133 | .2173 | .20 | .2106 | 11.9189 | .0155 |
| 6 | 3 | .7031 | 1.3876 | 7.0 | .1133 | .2275 | .20 | .2106 | 12.0983 | .0273 |
| 6 | 4 | .7031 | 1.6290 | 7.0 | .1133 | .2327 | .20 | .2106 | 12.3342 | .0427 |
| 6 | 5 | .7031 | 1.9193 | 7.0 | .1133 | .2427 | .20 | .2106 | 12.5520 | .0576 |
| 6 | 6 | .7031 | 2.1041 | 7.0 | .1133 | .2581 | .20 | .2106 | 12.5411 | .0580 |
| 7 | 1 | .7912 | .9766 | 7.0 | .1275 | .2017 | .20 | .2106 | 11.8515 | .0112 |
| 7 | 2 | .7912 | 1.1312 | 7.0 | .1275 | .2173 | .20 | .2106 | 11.8114 | .0089 |
| 7 | 3 | .7912 | 1.3876 | 7.0 | .1275 | .2275 | .20 | .2106 | 11.9880 | .0208 |
| 7 | 4 | .7912 | 1.6290 | 7.0 | .1275 | .2327 | .20 | .2106 | 12.2213 | .0361 |
| 7 | 5 | .7912 | 1.9193 | 7.0 | .1275 | .2427 | .20 | .2106 | 12.4368 | .0510 |
| 7 | 6 | .7912 | 2.1041 | 7.0 | .1275 | .2581 | .20 | .2106 | 12.4281 | .0514 |
| 8 | 1 | .8081 | .9766 | 7.0 | .1465 | .2017 | .20 | .2106 | 11.7102 | .0023 |
| 8 | 2 | .8081 | 1.1312 | 7.0 | .1465 | .2173 | .20 | .2106 | 11.6739 | .0000 |
| 8 | 3 | .8081 | 1.3876 | 7.0 | .1465 | .2275 | .20 | .2106 | 11.8489 | .0117 |
| 8 | 4 | .8081 | 1.6290 | 7.0 | .1465 | .2327 | .20 | .2106 | 12.0766 | .0272 |
| 8 | 5 | .8081 | 1.9193 | 7.0 | .1465 | .2427 | .20 | .2106 | 12.2885 | .0421 |
| 8 | 6 | .8081 | 2.1041 | 7.0 | .1465 | .2581 | .20 | .2106 | 12.2831 | .0425 |
| 1 | TC | .1973 | .5600 | 7.0 | .0318 | .1229 | .20 | .2106 | 13.7224 | .0991 |
| 2 | TC | .3103 | .5600 | 7.0 | .0500 | .1229 | .20 | .2106 | 13.4880 | .0906 |
| 3 | TC | .3886 | .5600 | 7.0 | .0644 | .1229 | .20 | .2106 | 13.3125 | .0839 |
| 4 | TC | .5194 | .5600 | 7.0 | .0837 | .1229 | .20 | .2106 | 13.0804 | .0748 |
| 5 | TC | .6361 | .5600 | 7.0 | .1025 | .1229 | .20 | .2106 | 12.8869 | .0660 |
| 6 | TC | .7031 | .5600 | 7.0 | .1133 | .1229 | .20 | .2106 | 12.7753 | .0610 |
| 7 | TC | .7912 | .5600 | 7.0 | .1275 | .1229 | .20 | .2106 | 12.6341 | .0543 |

S/PT/WIND

MINIMUM SCALING FACTOR= 11.4768

| I | J | AF | AR | W2 | MF | MR | D1 | D2 | AJ | ND |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | .1973 | .9766 | 7.0 | .0318 | .2017 | .20 | .2239 | 12.4336 | .0548 |
| 1 | 2 | .1973 | 1.1312 | 7.0 | .0318 | .2173 | .20 | .2239 | 12.3751 | .0526 |
| 1 | 3 | .1973 | 1.3876 | 7.0 | .0318 | .2275 | .20 | .2239 | 12.5657 | .0648 |
| 1 | 4 | .1973 | 1.6290 | 7.0 | .0318 | .2327 | .20 | .2239 | 12.8214 | .0806 |
| 1 | 5 | .1973 | 1.9193 | 7.0 | .0318 | .2427 | .20 | .2239 | 13.0535 | .0959 |
| 1 | 6 | .1973 | 2.1041 | 7.0 | .0318 | .2581 | .20 | .2239 | 13.0308 | .0986 |
| 2 | 1 | .3103 | .9766 | 7.0 | .0500 | .2017 | .20 | .2239 | 12.2659 | .0464 |
| 2 | 2 | .3103 | 1.1312 | 7.0 | .0500 | .2173 | .20 | .2239 | 12.2128 | .0443 |
| 2 | 3 | .3103 | 1.3876 | 7.0 | .0500 | .2275 | .20 | .2239 | 12.4007 | .0564 |
| 2 | 4 | .3103 | 1.6290 | 7.0 | .0500 | .2327 | .20 | .2239 | 12.6511 | .0723 |
| 2 | 5 | .3103 | 1.9193 | 7.0 | .0500 | .2427 | .20 | .2239 | 12.8797 | .0875 |
| 2 | 6 | .3103 | 2.1041 | 7.0 | .0500 | .2581 | .20 | .2239 | 12.8612 | .0882 |
| 3 | 1 | .3996 | .9766 | 7.0 | .0644 | .2017 | .20 | .2239 | 12.1394 | .0388 |
| 3 | 2 | .3996 | 1.1312 | 7.0 | .0644 | .2173 | .20 | .2239 | 12.0901 | .0377 |
| 3 | 3 | .3996 | 1.3876 | 7.0 | .0644 | .2275 | .20 | .2239 | 12.2760 | .0488 |
| 3 | 4 | .3996 | 1.6290 | 7.0 | .0644 | .2327 | .20 | .2239 | 12.5223 | .0656 |
| 3 | 5 | .3996 | 1.9193 | 7.0 | .0644 | .2427 | .20 | .2239 | 12.7481 | .0809 |
| 3 | 6 | .3996 | 2.1041 | 7.0 | .0644 | .2581 | .20 | .2239 | 12.7327 | .0816 |
| 4 | 1 | .5184 | .9766 | 7.0 | .0837 | .2017 | .20 | .2239 | 11.9780 | .0309 |
| 4 | 2 | .5184 | 1.1312 | 7.0 | .0837 | .2173 | .20 | .2239 | 11.9335 | .0288 |
| 4 | 3 | .5184 | 1.3876 | 7.0 | .0837 | .2275 | .20 | .2239 | 12.1167 | .0409 |
| 4 | 4 | .5184 | 1.6290 | 7.0 | .0837 | .2327 | .20 | .2239 | 12.3576 | .0568 |
| 4 | 5 | .5184 | 1.9193 | 7.0 | .0837 | .2427 | .20 | .2239 | 12.5799 | .0721 |
| 4 | 6 | .5184 | 2.1041 | 7.0 | .0837 | .2581 | .20 | .2239 | 12.5682 | .0728 |
| 5 | 1 | .6361 | .9766 | 7.0 | .1025 | .2017 | .20 | .2239 | 11.8290 | .0223 |
| 5 | 2 | .6361 | 1.1312 | 7.0 | .1025 | .2173 | .20 | .2239 | 11.7887 | .0202 |
| 5 | 3 | .6361 | 1.3876 | 7.0 | .1025 | .2275 | .20 | .2239 | 11.9693 | .0323 |
| 5 | 4 | .6361 | 1.6290 | 7.0 | .1025 | .2327 | .20 | .2239 | 12.2053 | .0481 |
| 5 | 5 | .6361 | 1.9193 | 7.0 | .1025 | .2427 | .20 | .2239 | 12.4241 | .0634 |
| 5 | 6 | .6361 | 2.1041 | 7.0 | .1025 | .2581 | .20 | .2239 | 12.4158 | .0641 |
| 6 | 1 | .7031 | .9766 | 7.0 | .1133 | .2017 | .20 | .2239 | 11.7467 | .0173 |
| 6 | 2 | .7031 | 1.1312 | 7.0 | .1133 | .2173 | .20 | .2239 | 11.7068 | .0152 |
| 6 | 3 | .7031 | 1.3876 | 7.0 | .1133 | .2275 | .20 | .2239 | 11.8879 | .0273 |
| 6 | 4 | .7031 | 1.6290 | 7.0 | .1133 | .2327 | .20 | .2239 | 12.1211 | .0432 |
| 6 | 5 | .7031 | 1.9193 | 7.0 | .1133 | .2427 | .20 | .2239 | 12.3379 | .0585 |
| 6 | 6 | .7031 | 2.1041 | 7.0 | .1133 | .2581 | .20 | .2239 | 12.3314 | .0592 |
| 7 | 1 | .7912 | .9766 | 7.0 | .1275 | .2017 | .20 | .2239 | 11.6422 | .0108 |
| 7 | 2 | .7912 | 1.1312 | 7.0 | .1275 | .2173 | .20 | .2239 | 11.6071 | .0087 |
| 7 | 3 | .7912 | 1.3876 | 7.0 | .1275 | .2275 | .20 | .2239 | 11.7843 | .0208 |
| 7 | 4 | .7912 | 1.6290 | 7.0 | .1275 | .2327 | .20 | .2239 | 12.0140 | .0367 |
| 7 | 5 | .7912 | 1.9193 | 7.0 | .1275 | .2427 | .20 | .2239 | 12.2263 | .0519 |
| 7 | 6 | .7912 | 2.1041 | 7.0 | .1275 | .2581 | .20 | .2239 | 12.2239 | .0527 |
| 8 | 1 | .8091 | .9766 | 7.0 | .1465 | .2017 | .20 | .2239 | 11.5084 | .0021 |
| 8 | 2 | .8091 | 1.1312 | 7.0 | .1465 | .2173 | .20 | .2239 | 11.4768 | .0000 |
| 8 | 3 | .8091 | 1.3876 | 7.0 | .1465 | .2275 | .20 | .2239 | 11.6514 | .0121 |
| 8 | 4 | .8091 | 1.6290 | 7.0 | .1465 | .2327 | .20 | .2239 | 11.8766 | .0279 |
| 8 | 5 | .8091 | 1.9193 | 7.0 | .1465 | .2427 | .20 | .2239 | 12.0875 | .0432 |
| 8 | 6 | .8091 | 2.1041 | 7.0 | .1465 | .2581 | .20 | .2239 | 12.0859 | .0439 |
| 1 | TC | .1973 | .5600 | 7.0 | .0318 | .1229 | .20 | .2239 | 13.4070 | .0973 |
| 2 | TC | .3103 | .5600 | 7.0 | .0500 | .1229 | .20 | .2239 | 13.1875 | .0889 |
| 3 | TC | .3996 | .5600 | 7.0 | .0644 | .1229 | .20 | .2239 | 13.0229 | .0823 |
| 4 | TC | .5184 | .5600 | 7.0 | .0837 | .1229 | .20 | .2239 | 12.8142 | .0734 |
| 5 | TC | .6361 | .5600 | 7.0 | .1025 | .1229 | .20 | .2239 | 12.6229 | .0648 |
| 6 | TC | .7031 | .5600 | 7.0 | .1133 | .1229 | .20 | .2239 | 12.5179 | .0598 |
| 7 | TC | .7812 | .5600 | 7.0 | .1275 | .1229 | .20 | .2239 | 12.3849 | .0533 |

VALUE/RANDOM

MINIMUM SCALING FACTOR= 12.1102

| I | J | AF | AR | WE | MF | MR | D1 | D2 | AJ | NO |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | .1973 | .9766 | 7.0 | .0318 | .2017 | .20 | .1827 | 13.2650 | .0587 |
| 1 | 2 | .1973 | 1.1312 | 7.0 | .0318 | .2173 | .20 | .1827 | 13.1821 | .0559 |
| 1 | 3 | .1973 | 1.3876 | 7.0 | .0318 | .2275 | .20 | .1827 | 13.3721 | .0668 |
| 1 | 4 | .1973 | 1.6290 | 7.0 | .0318 | .2327 | .20 | .1827 | 13.6376 | .0816 |
| 1 | 5 | .1973 | 1.8183 | 7.0 | .0318 | .2427 | .20 | .1827 | 13.6718 | .0956 |
| 1 | 6 | .1973 | 2.1041 | 7.0 | .0318 | .2581 | .20 | .1827 | 13.8290 | .0954 |
| 2 | 1 | .3103 | .9766 | 7.0 | .0500 | .2017 | .20 | .1827 | 13.0625 | .0498 |
| 2 | 2 | .3103 | 1.1312 | 7.0 | .0500 | .2173 | .20 | .1827 | 12.9869 | .0470 |
| 2 | 3 | .3103 | 1.3876 | 7.0 | .0500 | .2275 | .20 | .1827 | 13.1746 | .0580 |
| 2 | 4 | .3103 | 1.6290 | 7.0 | .0500 | .2327 | .20 | .1827 | 13.4344 | .0727 |
| 2 | 5 | .3103 | 1.8183 | 7.0 | .0500 | .2427 | .20 | .1827 | 13.6653 | .0867 |
| 2 | 6 | .3103 | 2.1041 | 7.0 | .0500 | .2581 | .20 | .1827 | 13.6282 | .0865 |
| 3 | 1 | .3896 | .9766 | 7.0 | .0644 | .2017 | .20 | .1827 | 12.9102 | .0428 |
| 3 | 2 | .3896 | 1.1312 | 7.0 | .0644 | .2173 | .20 | .1827 | 12.8398 | .0400 |
| 3 | 3 | .3896 | 1.3876 | 7.0 | .0644 | .2275 | .20 | .1827 | 13.0257 | .0510 |
| 3 | 4 | .3896 | 1.6290 | 7.0 | .0644 | .2327 | .20 | .1827 | 13.2812 | .0657 |
| 3 | 5 | .3896 | 1.8183 | 7.0 | .0644 | .2427 | .20 | .1827 | 13.5085 | .0797 |
| 3 | 6 | .3896 | 2.1041 | 7.0 | .0644 | .2581 | .20 | .1827 | 13.4766 | .0795 |
| 4 | 1 | .5194 | .9766 | 7.0 | .0837 | .2017 | .20 | .1827 | 12.7166 | .0334 |
| 4 | 2 | .5194 | 1.1312 | 7.0 | .0837 | .2173 | .20 | .1827 | 12.6526 | .0306 |
| 4 | 3 | .5194 | 1.3876 | 7.0 | .0837 | .2275 | .20 | .1827 | 12.8361 | .0415 |
| 4 | 4 | .5194 | 1.6290 | 7.0 | .0837 | .2327 | .20 | .1827 | 13.0659 | .0563 |
| 4 | 5 | .5194 | 1.8183 | 7.0 | .0837 | .2427 | .20 | .1827 | 13.3106 | .0703 |
| 4 | 6 | .5194 | 2.1041 | 7.0 | .0837 | .2581 | .20 | .1827 | 13.2829 | .0701 |
| 5 | 1 | .6361 | .9766 | 7.0 | .1025 | .2017 | .20 | .1827 | 12.5385 | .0242 |
| 5 | 2 | .6361 | 1.1312 | 7.0 | .1025 | .2173 | .20 | .1827 | 12.4601 | .0214 |
| 5 | 3 | .6361 | 1.3876 | 7.0 | .1025 | .2275 | .20 | .1827 | 12.6612 | .0324 |
| 5 | 4 | .6361 | 1.6290 | 7.0 | .1025 | .2327 | .20 | .1827 | 12.9058 | .0471 |
| 5 | 5 | .6361 | 1.8183 | 7.0 | .1025 | .2427 | .20 | .1827 | 13.1273 | .0611 |
| 5 | 6 | .6361 | 2.1041 | 7.0 | .1025 | .2581 | .20 | .1827 | 13.1039 | .0608 |
| 6 | 1 | .7031 | .9766 | 7.0 | .1133 | .2017 | .20 | .1827 | 12.4404 | .0180 |
| 6 | 2 | .7031 | 1.1312 | 7.0 | .1133 | .2173 | .20 | .1827 | 12.3851 | .0161 |
| 6 | 3 | .7031 | 1.3876 | 7.0 | .1133 | .2275 | .20 | .1827 | 12.5648 | .0271 |
| 6 | 4 | .7031 | 1.6290 | 7.0 | .1133 | .2327 | .20 | .1827 | 12.8065 | .0418 |
| 6 | 5 | .7031 | 1.8183 | 7.0 | .1133 | .2427 | .20 | .1827 | 13.0261 | .0558 |
| 6 | 6 | .7031 | 2.1041 | 7.0 | .1133 | .2581 | .20 | .1827 | 13.0051 | .0557 |
| 7 | 1 | .7912 | .9766 | 7.0 | .1275 | .2017 | .20 | .1827 | 12.3160 | .0121 |
| 7 | 2 | .7912 | 1.1312 | 7.0 | .1275 | .2173 | .20 | .1827 | 12.2644 | .0092 |
| 7 | 3 | .7912 | 1.3876 | 7.0 | .1275 | .2275 | .20 | .1827 | 12.4424 | .0202 |
| 7 | 4 | .7912 | 1.6290 | 7.0 | .1275 | .2327 | .20 | .1827 | 12.6803 | .0349 |
| 7 | 5 | .7912 | 1.8183 | 7.0 | .1275 | .2427 | .20 | .1827 | 12.8974 | .0489 |
| 7 | 6 | .7912 | 2.1041 | 7.0 | .1275 | .2581 | .20 | .1827 | 12.8794 | .0488 |
| 8 | 1 | .9091 | .9766 | 7.0 | .1465 | .2017 | .20 | .1827 | 12.1572 | .0028 |
| 8 | 2 | .9091 | 1.1312 | 7.0 | .1465 | .2173 | .20 | .1827 | 12.1102 | .0000 |
| 8 | 3 | .9091 | 1.3876 | 7.0 | .1465 | .2275 | .20 | .1827 | 12.2858 | .0108 |
| 8 | 4 | .9091 | 1.6290 | 7.0 | .1465 | .2327 | .20 | .1827 | 12.5188 | .0257 |
| 8 | 5 | .9091 | 1.8183 | 7.0 | .1465 | .2427 | .20 | .1827 | 12.7327 | .0398 |
| 8 | 6 | .9091 | 2.1041 | 7.0 | .1465 | .2581 | .20 | .1827 | 12.7184 | .0385 |
| 1 | TC | .1973 | .5600 | 7.0 | .0318 | .1229 | .20 | .1827 | 14.4348 | .1031 |
| 2 | TC | .3103 | .5600 | 7.0 | .0500 | .1229 | .20 | .1827 | 14.1654 | .0942 |
| 3 | TC | .3896 | .5600 | 7.0 | .0644 | .1229 | .20 | .1827 | 13.8642 | .0872 |
| 4 | TC | .5194 | .5600 | 7.0 | .0837 | .1229 | .20 | .1827 | 13.7101 | .0778 |
| 5 | TC | .6361 | .5600 | 7.0 | .1025 | .1229 | .20 | .1827 | 13.4782 | .0686 |
| 6 | TC | .7031 | .5600 | 7.0 | .1133 | .1229 | .20 | .1827 | 13.3512 | .0634 |
| 7 | TC | .7912 | .5600 | 7.0 | .1275 | .1229 | .20 | .1827 | 13.1808 | .0565 |

VALUE/FMFS

MINIMUM SCALING FACTOR= 12.1869

| I | J | AF | AR | WR | MF | MR | D1 | D2 | AJ | ND |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | .1973 | .9766 | 7.0 | .0318 | .2017 | .20 | .1780 | 13.3869 | .0592 |
| 1 | 2 | .1973 | 1.1312 | 7.0 | .0318 | .2173 | .20 | .1780 | 13.2869 | .0562 |
| 1 | 3 | .1973 | 1.3876 | 7.0 | .0318 | .2275 | .20 | .1780 | 13.4707 | .0671 |
| 1 | 4 | .1973 | 1.6290 | 7.0 | .0318 | .2327 | .20 | .1780 | 13.7374 | .0817 |
| 1 | 5 | .1973 | 1.9193 | 7.0 | .0318 | .2427 | .20 | .1780 | 13.9718 | .0855 |
| 1 | 6 | .1973 | 2.1041 | 7.0 | .0318 | .2581 | .20 | .1780 | 13.9263 | .0953 |
| 2 | 1 | .3103 | .9766 | 7.0 | .0500 | .2017 | .20 | .1780 | 13.1800 | .0502 |
| 2 | 2 | .3103 | 1.1312 | 7.0 | .0500 | .2173 | .20 | .1780 | 13.0815 | .0473 |
| 2 | 3 | .3103 | 1.3876 | 7.0 | .0500 | .2275 | .20 | .1780 | 13.2691 | .0502 |
| 2 | 4 | .3103 | 1.6290 | 7.0 | .0500 | .2327 | .20 | .1780 | 13.5500 | .0788 |
| 2 | 5 | .3103 | 1.9193 | 7.0 | .0500 | .2427 | .20 | .1780 | 13.7611 | .0866 |
| 2 | 6 | .3103 | 2.1041 | 7.0 | .0500 | .2581 | .20 | .1780 | 13.7216 | .0864 |
| 3 | 1 | .3996 | .9766 | 7.0 | .0644 | .2017 | .20 | .1780 | 13.0045 | .0432 |
| 3 | 2 | .3996 | 1.1312 | 7.0 | .0644 | .2173 | .20 | .1780 | 12.9313 | .0402 |
| 3 | 3 | .3996 | 1.3876 | 7.0 | .0644 | .2275 | .20 | .1780 | 13.1171 | .0511 |
| 3 | 4 | .3996 | 1.6290 | 7.0 | .0644 | .2327 | .20 | .1780 | 13.3737 | .0657 |
| 3 | 5 | .3996 | 1.9193 | 7.0 | .0644 | .2427 | .20 | .1780 | 13.6022 | .0795 |
| 3 | 6 | .3996 | 2.1041 | 7.0 | .0644 | .2581 | .20 | .1780 | 13.5670 | .0793 |
| 4 | 1 | .5194 | .9766 | 7.0 | .0837 | .2017 | .20 | .1780 | 12.8067 | .0337 |
| 4 | 2 | .5194 | 1.1312 | 7.0 | .0837 | .2173 | .20 | .1780 | 12.7402 | .0308 |
| 4 | 3 | .5194 | 1.3876 | 7.0 | .0837 | .2275 | .20 | .1780 | 12.9236 | .0416 |
| 4 | 4 | .5194 | 1.6290 | 7.0 | .0837 | .2327 | .20 | .1780 | 13.1745 | .0562 |
| 4 | 5 | .5194 | 1.9193 | 7.0 | .0837 | .2427 | .20 | .1780 | 13.3986 | .0700 |
| 4 | 6 | .5194 | 2.1041 | 7.0 | .0837 | .2581 | .20 | .1780 | 13.3686 | .0698 |
| 5 | 1 | .6361 | .9766 | 7.0 | .1025 | .2017 | .20 | .1780 | 12.6248 | .0245 |
| 5 | 2 | .6361 | 1.1312 | 7.0 | .1025 | .2173 | .20 | .1780 | 12.5642 | .0216 |
| 5 | 3 | .6361 | 1.3876 | 7.0 | .1025 | .2275 | .20 | .1780 | 12.7453 | .0324 |
| 5 | 4 | .6361 | 1.6290 | 7.0 | .1025 | .2327 | .20 | .1780 | 12.9908 | .0470 |
| 5 | 5 | .6361 | 1.9193 | 7.0 | .1025 | .2427 | .20 | .1780 | 13.2126 | .0608 |
| 5 | 6 | .6361 | 2.1041 | 7.0 | .1025 | .2581 | .20 | .1780 | 13.1873 | .0606 |
| 6 | 1 | .7031 | .9766 | 7.0 | .1133 | .2017 | .20 | .1780 | 12.5248 | .0192 |
| 6 | 2 | .7031 | 1.1312 | 7.0 | .1133 | .2173 | .20 | .1780 | 12.4672 | .0163 |
| 6 | 3 | .7031 | 1.3876 | 7.0 | .1133 | .2275 | .20 | .1780 | 12.6470 | .0271 |
| 6 | 4 | .7031 | 1.6290 | 7.0 | .1133 | .2327 | .20 | .1780 | 12.8886 | .0417 |
| 6 | 5 | .7031 | 1.9193 | 7.0 | .1133 | .2427 | .20 | .1780 | 13.1085 | .0555 |
| 6 | 6 | .7031 | 2.1041 | 7.0 | .1133 | .2581 | .20 | .1780 | 13.0867 | .0553 |
| 7 | 1 | .7912 | .9766 | 7.0 | .1275 | .2017 | .20 | .1780 | 12.3879 | .0122 |
| 7 | 2 | .7912 | 1.1312 | 7.0 | .1275 | .2173 | .20 | .1780 | 12.3442 | .0093 |
| 7 | 3 | .7912 | 1.3876 | 7.0 | .1275 | .2275 | .20 | .1780 | 12.5222 | .0201 |
| 7 | 4 | .7912 | 1.6290 | 7.0 | .1275 | .2327 | .20 | .1780 | 12.7610 | .0347 |
| 7 | 5 | .7912 | 1.9193 | 7.0 | .1275 | .2427 | .20 | .1780 | 12.9784 | .0485 |
| 7 | 6 | .7912 | 2.1041 | 7.0 | .1275 | .2581 | .20 | .1780 | 12.9587 | .0483 |
| 8 | 1 | .8691 | .9766 | 7.0 | .1465 | .2017 | .20 | .1780 | 12.2358 | .0029 |
| 8 | 2 | .8691 | 1.1312 | 7.0 | .1465 | .2173 | .20 | .1780 | 12.1869 | .0000 |
| 8 | 3 | .8691 | 1.3876 | 7.0 | .1465 | .2275 | .20 | .1780 | 12.3626 | .0108 |
| 8 | 4 | .8691 | 1.6290 | 7.0 | .1465 | .2327 | .20 | .1780 | 12.5965 | .0254 |
| 8 | 5 | .8691 | 1.9193 | 7.0 | .1465 | .2427 | .20 | .1780 | 12.8107 | .0392 |
| 8 | 6 | .8691 | 2.1041 | 7.0 | .1465 | .2581 | .20 | .1780 | 12.7847 | .0390 |
| 1 | TC | .1973 | .5600 | 7.0 | .0318 | .1229 | .20 | .1780 | 14.5622 | .1038 |
| 2 | TC | .3103 | .5600 | 7.0 | .0500 | .1229 | .20 | .1780 | 14.2862 | .0948 |
| 3 | TC | .3996 | .5600 | 7.0 | .0644 | .1229 | .20 | .1780 | 14.0803 | .0878 |
| 4 | TC | .5194 | .5600 | 7.0 | .0837 | .1229 | .20 | .1780 | 13.8203 | .0783 |
| 5 | TC | .6361 | .5600 | 7.0 | .1025 | .1229 | .20 | .1780 | 13.5831 | .0691 |
| 6 | TC | .7031 | .5600 | 7.0 | .1133 | .1229 | .20 | .1780 | 13.4534 | .0638 |
| 7 | TC | .7912 | .5600 | 7.0 | .1275 | .1229 | .20 | .1780 | 13.2896 | .0568 |

VALUE/NINO

MINIMUM SCALING FACTOR= 11.8951

| I | J | AF | AR | WR | MF | MR | D1 | D2 | AJ | ND |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | .1873 | .9766 | 7.0 | .0318 | .2017 | .20 | .1862 | 12.9808 | .0574 |
| 1 | 2 | .1873 | 1.1312 | 7.0 | .0318 | .2173 | .20 | .1862 | 12.9084 | .0548 |
| 1 | 3 | .1873 | 1.3876 | 7.0 | .0318 | .2275 | .20 | .1862 | 13.0867 | .0682 |
| 1 | 4 | .1873 | 1.6280 | 7.0 | .0318 | .2327 | .20 | .1862 | 13.3590 | .0813 |
| 1 | 5 | .1873 | 1.9183 | 7.0 | .0318 | .2427 | .20 | .1862 | 13.5928 | .0957 |
| 1 | 6 | .1873 | 2.1041 | 7.0 | .0318 | .2581 | .20 | .1862 | 13.5580 | .0958 |
| 2 | 1 | .3103 | .9766 | 7.0 | .0500 | .2017 | .20 | .1862 | 12.7903 | .0487 |
| 2 | 2 | .3103 | 1.1312 | 7.0 | .0500 | .2173 | .20 | .1862 | 12.7226 | .0461 |
| 2 | 3 | .3103 | 1.3876 | 7.0 | .0500 | .2275 | .20 | .1862 | 12.9106 | .0575 |
| 2 | 4 | .3103 | 1.6280 | 7.0 | .0500 | .2327 | .20 | .1862 | 13.1873 | .0726 |
| 2 | 5 | .3103 | 1.9183 | 7.0 | .0500 | .2427 | .20 | .1862 | 13.3875 | .0870 |
| 2 | 6 | .3103 | 2.1041 | 7.0 | .0500 | .2581 | .20 | .1862 | 13.3870 | .0871 |
| 3 | 1 | .3836 | .9766 | 7.0 | .0644 | .2017 | .20 | .1862 | 12.6471 | .0418 |
| 3 | 2 | .3836 | 1.1312 | 7.0 | .0644 | .2173 | .20 | .1862 | 12.5841 | .0392 |
| 3 | 3 | .3836 | 1.3876 | 7.0 | .0644 | .2275 | .20 | .1862 | 12.7702 | .0506 |
| 3 | 4 | .3836 | 1.6280 | 7.0 | .0644 | .2327 | .20 | .1862 | 13.0226 | .0657 |
| 3 | 5 | .3836 | 1.9183 | 7.0 | .0644 | .2427 | .20 | .1862 | 13.2502 | .0801 |
| 3 | 6 | .3836 | 2.1041 | 7.0 | .0644 | .2581 | .20 | .1862 | 13.2234 | .0802 |
| 4 | 1 | .5184 | .9766 | 7.0 | .0837 | .2017 | .20 | .1862 | 12.4647 | .0326 |
| 4 | 2 | .5184 | 1.1312 | 7.0 | .0837 | .2173 | .20 | .1862 | 12.4076 | .0300 |
| 4 | 3 | .5184 | 1.3876 | 7.0 | .0837 | .2275 | .20 | .1862 | 12.5811 | .0413 |
| 4 | 4 | .5184 | 1.6280 | 7.0 | .0837 | .2327 | .20 | .1862 | 12.8380 | .0564 |
| 4 | 5 | .5184 | 1.9183 | 7.0 | .0837 | .2427 | .20 | .1862 | 13.0621 | .0706 |
| 4 | 6 | .5184 | 2.1041 | 7.0 | .0837 | .2581 | .20 | .1862 | 13.0398 | .0710 |
| 5 | 1 | .6361 | .9766 | 7.0 | .1025 | .2017 | .20 | .1862 | 12.2868 | .0236 |
| 5 | 2 | .6361 | 1.1312 | 7.0 | .1025 | .2173 | .20 | .1862 | 12.2440 | .0210 |
| 5 | 3 | .6361 | 1.3876 | 7.0 | .1025 | .2275 | .20 | .1862 | 12.4259 | .0324 |
| 5 | 4 | .6361 | 1.6280 | 7.0 | .1025 | .2327 | .20 | .1862 | 12.6878 | .0475 |
| 5 | 5 | .6361 | 1.9183 | 7.0 | .1025 | .2427 | .20 | .1862 | 12.8883 | .0618 |
| 5 | 6 | .6361 | 2.1041 | 7.0 | .1025 | .2581 | .20 | .1862 | 12.8702 | .0620 |
| 6 | 1 | .7031 | .9766 | 7.0 | .1133 | .2017 | .20 | .1862 | 12.2043 | .0184 |
| 6 | 2 | .7031 | 1.1312 | 7.0 | .1133 | .2173 | .20 | .1862 | 12.1550 | .0158 |
| 6 | 3 | .7031 | 1.3876 | 7.0 | .1133 | .2275 | .20 | .1862 | 12.3347 | .0272 |
| 6 | 4 | .7031 | 1.6280 | 7.0 | .1133 | .2327 | .20 | .1862 | 12.5735 | .0423 |
| 6 | 5 | .7031 | 1.9183 | 7.0 | .1133 | .2427 | .20 | .1862 | 12.7823 | .0567 |
| 6 | 6 | .7031 | 2.1041 | 7.0 | .1133 | .2581 | .20 | .1862 | 12.7764 | .0568 |
| 7 | 1 | .7812 | .9766 | 7.0 | .1275 | .2017 | .20 | .1862 | 12.0868 | .0116 |
| 7 | 2 | .7812 | 1.1312 | 7.0 | .1275 | .2173 | .20 | .1862 | 12.0410 | .0080 |
| 7 | 3 | .7812 | 1.3876 | 7.0 | .1275 | .2275 | .20 | .1862 | 12.2188 | .0204 |
| 7 | 4 | .7812 | 1.6280 | 7.0 | .1275 | .2327 | .20 | .1862 | 12.4539 | .0355 |
| 7 | 5 | .7812 | 1.9183 | 7.0 | .1275 | .2427 | .20 | .1862 | 12.6702 | .0499 |
| 7 | 6 | .7812 | 2.1041 | 7.0 | .1275 | .2581 | .20 | .1862 | 12.6570 | .0500 |
| 8 | 1 | .9091 | .9766 | 7.0 | .1465 | .2017 | .20 | .1862 | 11.9367 | .0026 |
| 8 | 2 | .9091 | 1.1312 | 7.0 | .1465 | .2173 | .20 | .1862 | 11.8951 | .0000 |
| 8 | 3 | .9091 | 1.3876 | 7.0 | .1465 | .2275 | .20 | .1862 | 12.0705 | .0113 |
| 8 | 4 | .9091 | 1.6280 | 7.0 | .1465 | .2327 | .20 | .1862 | 12.3006 | .0264 |
| 8 | 5 | .9091 | 1.9183 | 7.0 | .1465 | .2427 | .20 | .1862 | 12.5138 | .0408 |
| 8 | 6 | .9091 | 2.1041 | 7.0 | .1465 | .2581 | .20 | .1862 | 12.5039 | .0409 |
| 1 | TC | .1873 | .5600 | 7.0 | .0318 | .1229 | .20 | .1862 | 14.0811 | .1012 |
| 2 | TC | .3103 | .5600 | 7.0 | .0500 | .1229 | .20 | .1862 | 13.8293 | .0825 |
| 3 | TC | .3836 | .5600 | 7.0 | .0644 | .1229 | .20 | .1862 | 13.6411 | .0856 |
| 4 | TC | .5184 | .5600 | 7.0 | .0837 | .1229 | .20 | .1862 | 13.4031 | .0764 |
| 5 | TC | .6361 | .5600 | 7.0 | .1025 | .1229 | .20 | .1862 | 13.1854 | .0674 |
| 6 | TC | .7031 | .5600 | 7.0 | .1133 | .1229 | .20 | .1862 | 13.0662 | .0622 |
| 7 | TC | .7812 | .5600 | 7.0 | .1275 | .1229 | .20 | .1862 | 12.9155 | .0554 |

VALUE/WING

MINIMUM SCALING FACTOR= 11.738

| I | J | AF | AR | WB | MF | MR | D1 | D2 | AJ | NO |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | .1973 | .9766 | 7.0 | .0318 | .2017 | .20 | .2065 | 12.7717 | .0564 |
| 1 | 2 | .1973 | 1.1312 | 7.0 | .0318 | .2173 | .20 | .2065 | 12.7038 | .0540 |
| 1 | 3 | .1973 | 1.3876 | 7.0 | .0318 | .2275 | .20 | .2065 | 12.8841 | .0657 |
| 1 | 4 | .1973 | 1.6290 | 7.0 | .0318 | .2327 | .20 | .2065 | 13.1539 | .0810 |
| 1 | 5 | .1973 | 1.9193 | 7.0 | .0318 | .2427 | .20 | .2065 | 13.3870 | .0958 |
| 1 | 6 | .1973 | 2.1041 | 7.0 | .0318 | .2581 | .20 | .2065 | 13.3564 | .0961 |
| 2 | 1 | .3103 | .9766 | 7.0 | .0500 | .2017 | .20 | .2065 | 12.5802 | .0479 |
| 2 | 2 | .3103 | 1.1312 | 7.0 | .0500 | .2173 | .20 | .2065 | 12.5281 | .0454 |
| 2 | 3 | .3103 | 1.3876 | 7.0 | .0500 | .2275 | .20 | .2065 | 12.7182 | .0571 |
| 2 | 4 | .3103 | 1.6290 | 7.0 | .0500 | .2327 | .20 | .2065 | 12.9705 | .0724 |
| 2 | 5 | .3103 | 1.9193 | 7.0 | .0500 | .2427 | .20 | .2065 | 13.2008 | .0872 |
| 2 | 6 | .3103 | 2.1041 | 7.0 | .0500 | .2581 | .20 | .2065 | 13.1743 | .0875 |
| 3 | 1 | .3996 | .9766 | 7.0 | .0644 | .2017 | .20 | .2065 | 12.4534 | .0411 |
| 3 | 2 | .3996 | 1.1312 | 7.0 | .0644 | .2173 | .20 | .2065 | 12.3858 | .0386 |
| 3 | 3 | .3996 | 1.3876 | 7.0 | .0644 | .2275 | .20 | .2065 | 12.5819 | .0503 |
| 3 | 4 | .3996 | 1.6290 | 7.0 | .0644 | .2327 | .20 | .2065 | 12.8320 | .0657 |
| 3 | 5 | .3996 | 1.9193 | 7.0 | .0644 | .2427 | .20 | .2065 | 13.0589 | .0804 |
| 3 | 6 | .3996 | 2.1041 | 7.0 | .0644 | .2581 | .20 | .2065 | 13.0366 | .0807 |
| 4 | 1 | .5194 | .9766 | 7.0 | .0837 | .2017 | .20 | .2065 | 12.2782 | .0320 |
| 4 | 2 | .5194 | 1.1312 | 7.0 | .0837 | .2173 | .20 | .2065 | 12.2269 | .0295 |
| 4 | 3 | .5194 | 1.3876 | 7.0 | .0837 | .2275 | .20 | .2065 | 12.4104 | .0412 |
| 4 | 4 | .5194 | 1.6290 | 7.0 | .0837 | .2327 | .20 | .2065 | 12.6551 | .0566 |
| 4 | 5 | .5194 | 1.9193 | 7.0 | .0837 | .2427 | .20 | .2065 | 12.8785 | .0713 |
| 4 | 6 | .5194 | 2.1041 | 7.0 | .0837 | .2581 | .20 | .2065 | 12.8604 | .0716 |
| 5 | 1 | .6361 | .9766 | 7.0 | .1025 | .2017 | .20 | .2065 | 12.1186 | .0231 |
| 5 | 2 | .6361 | 1.1312 | 7.0 | .1025 | .2173 | .20 | .2065 | 12.0711 | .0207 |
| 5 | 3 | .6361 | 1.3876 | 7.0 | .1025 | .2275 | .20 | .2065 | 12.2521 | .0323 |
| 5 | 4 | .6361 | 1.6290 | 7.0 | .1025 | .2327 | .20 | .2065 | 12.4917 | .0477 |
| 5 | 5 | .6361 | 1.9193 | 7.0 | .1025 | .2427 | .20 | .2065 | 12.7117 | .0624 |
| 5 | 6 | .6361 | 2.1041 | 7.0 | .1025 | .2581 | .20 | .2065 | 12.6874 | .0628 |
| 6 | 1 | .7031 | .9766 | 7.0 | .1133 | .2017 | .20 | .2065 | 12.0300 | .0180 |
| 6 | 2 | .7031 | 1.1312 | 7.0 | .1133 | .2173 | .20 | .2065 | 11.9052 | .0156 |
| 6 | 3 | .7031 | 1.3876 | 7.0 | .1133 | .2275 | .20 | .2065 | 12.1647 | .0272 |
| 6 | 4 | .7031 | 1.6290 | 7.0 | .1133 | .2327 | .20 | .2065 | 12.4014 | .0426 |
| 6 | 5 | .7031 | 1.9193 | 7.0 | .1133 | .2427 | .20 | .2065 | 12.6195 | .0574 |
| 6 | 6 | .7031 | 2.1041 | 7.0 | .1133 | .2581 | .20 | .2065 | 12.6072 | .0577 |
| 7 | 1 | .7912 | .9766 | 7.0 | .1275 | .2017 | .20 | .2065 | 11.9176 | .0113 |
| 7 | 2 | .7912 | 1.1312 | 7.0 | .1275 | .2173 | .20 | .2065 | 11.8759 | .0089 |
| 7 | 3 | .7912 | 1.3876 | 7.0 | .1275 | .2275 | .20 | .2065 | 12.0535 | .0206 |
| 7 | 4 | .7912 | 1.6290 | 7.0 | .1275 | .2327 | .20 | .2065 | 12.2866 | .0359 |
| 7 | 5 | .7912 | 1.9193 | 7.0 | .1275 | .2427 | .20 | .2065 | 12.5022 | .0507 |
| 7 | 6 | .7912 | 2.1041 | 7.0 | .1275 | .2581 | .20 | .2065 | 12.4924 | .0510 |
| 8 | 1 | .9091 | .9766 | 7.0 | .1465 | .2017 | .20 | .2065 | 11.7738 | .0024 |
| 8 | 2 | .9091 | 1.1312 | 7.0 | .1465 | .2173 | .20 | .2065 | 11.7360 | .0000 |
| 8 | 3 | .9091 | 1.3876 | 7.0 | .1465 | .2275 | .20 | .2065 | 11.9112 | .0116 |
| 8 | 4 | .9091 | 1.6290 | 7.0 | .1465 | .2327 | .20 | .2065 | 12.1386 | .0270 |
| 8 | 5 | .9091 | 1.9193 | 7.0 | .1465 | .2427 | .20 | .2065 | 12.3518 | .0417 |
| 8 | 6 | .9091 | 2.1041 | 7.0 | .1465 | .2581 | .20 | .2065 | 12.3452 | .0421 |
| 1 | TC | .1973 | .5600 | 7.0 | .0318 | .1229 | .20 | .2065 | 13.8227 | .0997 |
| 2 | TC | .3103 | .5600 | 7.0 | .0500 | .1229 | .20 | .2065 | 13.5835 | .0912 |
| 3 | TC | .3996 | .5600 | 7.0 | .0644 | .1229 | .20 | .2065 | 13.4045 | .0844 |
| 4 | TC | .5194 | .5600 | 7.0 | .0837 | .1229 | .20 | .2065 | 13.1779 | .0753 |
| 5 | TC | .6361 | .5600 | 7.0 | .1025 | .1229 | .20 | .2065 | 12.9705 | .0684 |
| 6 | TC | .7031 | .5600 | 7.0 | .1133 | .1229 | .20 | .2065 | 12.8568 | .0613 |
| 7 | TC | .7912 | .5600 | 7.0 | .1275 | .1229 | .20 | .2065 | 12.7130 | .0546 |

# XIII. APPENDIX B: PROCESSING TIMES AND DUE-DATES

The following data present the processing times and due-dates for seven part families. The data were adjusted by a time scaling factor for each of twenty-eight decision rule sets. The reader should be noted that all time values are in minutes.

* DECISION RULE SET=RANDOM/RANDOM
* TIME SCALING FACTOR= 12.2087

| PART | ORIGINAL PROCESSING TIME | ADJUSTED PROCESSING TIME | ORIGINAL DUE-DATE | ADJUSTED DUE-DATE |
|---|---|---|---|---|
| 1 | 47.8 | 3.91588226 | 610.2 | 49.9889405 |
| 2 | 82.8 | 6.78318007 | 745.2 | 61.0484406 |
| 3 | 23 | 1.88421113 | 387 | 31.7038003 |
| 4 | 11.2 | .917528880 | 100.8 | 8.25776088 |
| 5 | 14.4 | 1.17888801 | 308.8 | 25.3831203 |
| 6 | 160.4 | 13.1403248 | 1443.6 | 118.262821 |
| 7 | 20.2 | 1.65482891 | 181.8 | 14.8834802 |

* TURNING CELL TIME

| LATHE 1 | LATHE 2 | WASHER | MINI-MOVER-5 |
|---|---|---|---|
| .494180336 | .227826980 | .142317127 | .7842 |

* DECISION RULE SET=RANDOM/FMFS
* TIME SCALING FACTOR= 12.2913

| PART | ORIGINAL PROCESSING TIME | ADJUSTED PROCESSING TIME | ORIGINAL DUE-DATE | ADJUSTED DUE-DATE |
|---|---|---|---|---|
| 1 | 47.8 | 3.88892857 | 610.2 | 49.6448708 |
| 2 | 82.8 | 6.73647214 | 745.2 | 60.6282492 |
| 3 | 23 | 1.87124226 | 387 | 31.485685 |
| 4 | 11.2 | .911213622 | 100.8 | 8.20092261 |
| 5 | 14.4 | 1.17156037 | 308.8 | 25.168548 |
| 6 | 160.4 | 13.0498808 | 1443.6 | 117.448927 |
| 7 | 20.2 | 1.64343886 | 181.8 | 14.7809497 |

* TURNING CELL TIME

| LATHE 1 | LATHE 2 | WASHER | MINI-MOVER-5 |
|---|---|---|---|
| .477709502 | .224813348 | .140438333 | .7842 |

* DECISION RULE SET=RANDOM/NINQ
* TIME SCALING FACTOR= 12.0795

| PART | ORIGINAL PROCESSING TIME | ADJUSTED PROCESSING TIME | ORIGINAL DUE-DATE | ADJUSTED DUE-DATE |
|---|---|---|---|---|
| 1 | 47.8 | 3.85711743 | 610.2 | 50.5153358 |
| 2 | 82.8 | 6.85456836 | 745.2 | 61.6812852 |
| 3 | 23 | 1.80405232 | 387 | 32.0377489 |
| 4 | 11.2 | .827180285 | 100.8 | 8.34471826 |
| 5 | 14.4 | 1.18210232 | 308.6 | 25.8301888 |
| 6 | 160.4 | 13.2760853 | 1443.6 | 119.500258 |
| 7 | 20.2 | 1.67225485 | 181.8 | 15.0502918 |

* TURNING CELL TIME

| LATHE 1 | LATHE 2 | WASHER | MINI-MOVER-5 |
|---|---|---|---|
| .483877789 | .232420489 | .145181512 | .7842 |

* DECISION RULE SET=RANDOM/WINQ
* TIME SCALING FACTOR= 11.8826

| PART | ORIGINAL PROCESSING TIME | ADJUSTED PROCESSING TIME | ORIGINAL DUE-DATE | ADJUSTED DUE-DATE |
|---|---|---|---|---|
| 1 | 47.8 | 4.02268864 | 610.2 | 51.3523876 |
| 2 | 82.8 | 6.86817185 | 745.2 | 62.7135476 |
| 3 | 23 | 1.93560332 | 387 | 32.5686298 |
| 4 | 11.2 | .84255466 | 100.8 | 8.48288195 |
| 5 | 14.4 | 1.21185589 | 308.6 | 26.0549038 |
| 6 | 160.4 | 13.4887282 | 1443.6 | 121.488563 |
| 7 | 20.2 | 1.69886465 | 181.8 | 15.2886819 |

* TURNING CELL TIME

| LATHE 1 | LATHE 2 | WASHER | MINI-MOVER-5 |
|---|---|---|---|
| .508425513 | .239745517 | .148762291 | .7842 |

* DECISION RULE SET=FSFS/RANDOM
* TIME SCALING FACTOR= 12.0795

| PART | ORIGINAL PROCESSING TIME | ADJUSTED PROCESSING TIME | ORIGINAL DUE-DATE | ADJUSTED DUE-DATE |
|---|---|---|---|---|
| 1 | 47.8 | 3.95711743 | 610.2 | 50.5153359 |
| 2 | 82.8 | 6.85458836 | 745.2 | 61.6912952 |
| 3 | 23 | 1.90405232 | 387 | 32.0377499 |
| 4 | 11.2 | .927190695 | 100.8 | 8.34471626 |
| 5 | 14.4 | 1.19210232 | 309.6 | 25.6301999 |
| 6 | 160.4 | 13.2786953 | 1443.6 | 119.508258 |
| 7 | 20.2 | 1.67225465 | 181.8 | 15.0502918 |

* TURNING CELL TIME

| LATHE 1 | LATHE 2 | WASHER | MINI-MOVER-5 |
|---|---|---|---|
| .483877725 | .232428428 | .145181512 | .7842 |

* DECISION RULE SET=FSFS/FMFS
* TIME SCALING FACTOR= 12.1607

| PART | ORIGINAL PROCESSING TIME | ADJUSTED PROCESSING TIME | ORIGINAL DUE-DATE | ADJUSTED DUE-DATE |
|---|---|---|---|---|
| 1 | 47.8 | 3.93069478 | 610.2 | 50.1780325 |
| 2 | 82.8 | 6.80881858 | 745.2 | 61.2793672 |
| 3 | 23 | 1.89133849 | 387 | 31.8238259 |
| 4 | 11.2 | .920999613 | 100.8 | 8.28899652 |
| 5 | 14.4 | 1.18414236 | 309.6 | 25.4590608 |
| 6 | 160.4 | 13.1900302 | 1443.6 | 118.710272 |
| 7 | 20.2 | 1.66108859 | 181.8 | 14.9497973 |

* TURNING CELL TIME

| LATHE 1 | LATHE 2 | WASHER | MINI-MOVER-5 |
|---|---|---|---|
| .487612576 | .229479926 | .143348685 | .7842 |

* DECISION RULE SET=FSFS/NINQ
* TIME SCALING FACTOR= 11.9818

| PART | ORIGINAL PROCESSING TIME | ADJUSTED PROCESSING TIME | ORIGINAL DUE-DATE | ADJUSTED DUE-DATE |
|---|---|---|---|---|
| 1 | 47.8 | 3.9893839 | 618.2 | 50.9272397 |
| 2 | 82.8 | 6.9104809 | 745.2 | 62.1943281 |
| 3 | 23 | 1.91957803 | 387 | 32.2988868 |
| 4 | 11.2 | .934751039 | 100.8 | 8.41275936 |
| 5 | 14.4 | 1.20182277 | 309.6 | 25.8391894 |
| 6 | 160.4 | 13.3869702 | 1443.6 | 120.482732 |
| 7 | 20.2 | 1.68589027 | 181.8 | 15.1730124 |

* TURNING CELL TIME

| LATHE 1 | LATHE 2 | WASHER | MINI-MOVER-5 |
|---|---|---|---|
| .501528528 | .236028042 | .147440714 | .7842 |

* DECISION RULE SET=FSFS/WINQ
* TIME SCALING FACTOR= 11.8085

| PART | ORIGINAL PROCESSING TIME | ADJUSTED PROCESSING TIME | ORIGINAL DUE-DATE | ADJUSTED DUE-DATE |
|---|---|---|---|---|
| 1 | 47.8 | 4.04861728 | 618.2 | 51.6833848 |
| 2 | 82.8 | 7.01308602 | 745.2 | 63.1177741 |
| 3 | 23 | 1.94807945 | 387 | 32.7785542 |
| 4 | 11.2 | .948629882 | 100.8 | 8.53766383 |
| 5 | 14.4 | 1.21966713 | 309.6 | 26.2228434 |
| 6 | 160.4 | 13.5857367 | 1443.6 | 122.27163 |
| 7 | 20.2 | 1.71092155 | 181.8 | 15.3982376 |

* TURNING CELL TIME

| LATHE 1 | LATHE 2 | WASHER | MINI-MOVER-5 |
|---|---|---|---|
| .515573532 | .242638894 | .151563703 | .7842 |

* DECISION RULE SET=SPT/RANDOM
* TIME SCALING FACTOR= 11.8966

| PART | ORIGINAL PROCESSING TIME | ADJUSTED PROCESSING TIME | ORIGINAL DUE-DATE | ADJUSTED DUE-DATE |
|---|---|---|---|---|
| 1 | 47.8 | 4.01795471 | 610.2 | 51.2918858 |
| 2 | 82.8 | 6.95997176 | 745.2 | 62.6397459 |
| 3 | 23 | 1.93332549 | 387 | 32.5303026 |
| 4 | 11.2 | .941445455 | 100.8 | 8.47300909 |
| 5 | 14.4 | 1.21042967 | 309.6 | 26.0242422 |
| 6 | 160.4 | 13.4826436 | 1443.6 | 121.345585 |
| 7 | 20.2 | 1.69796413 | 181.8 | 15.2816771 |

* TURNING CELL TIME

| LATHE 1 | LATHE 2 | WASHER | MINI-MOVER-5 |
|---|---|---|---|
| .506303637 | .239217258 | .149432303 | .7842 |

* DECISION RULE SET=SPT/FMFS
* TIME SCALING FACTOR= 12.1248

| PART | ORIGINAL PROCESSING TIME | ADJUSTED PROCESSING TIME | ORIGINAL DUE-DATE | ADJUSTED DUE-DATE |
|---|---|---|---|---|
| 1 | 47.8 | 3.94233307 | 610.2 | 50.3266033 |
| 2 | 82.8 | 6.82897862 | 745.2 | 61.4608076 |
| 3 | 23 | 1.89693851 | 387 | 31.9180523 |
| 4 | 11.2 | .923726577 | 100.8 | 8.3135392 |
| 5 | 14.4 | 1.18764846 | 309.6 | 25.5344418 |
| 6 | 160.4 | 13.2290842 | 1443.6 | 119.061758 |
| 7 | 20.2 | 1.66600686 | 181.8 | 14.9940618 |

* TURNING CELL TIME

| LATHE 1 | LATHE 2 | WASHER | MINI-MOVER-5 |
|---|---|---|---|
| .490372165 | .230778642 | .144160937 | .7842 |

* DECISION RULE SET=SPT/NINQ
* TIME SCALING FACTOR= 11.8469

| PART | ORIGINAL PROCESSING TIME | ADJUSTED PROCESSING TIME | ORIGINAL DUE-DATE | ADJUSTED DUE-DATE |
|---|---|---|---|---|
| 1 | 47.8 | 4.03484485 | 610.2 | 51.5075801 |
| 2 | 82.8 | 6.98922916 | 745.2 | 62.9030625 |
| 3 | 23 | 1.94145954 | 387 | 32.6670493 |
| 4 | 11.2 | .945402978 | 100.8 | 8.50862681 |
| 5 | 14.4 | 1.21551812 | 309.6 | 26.1326395 |
| 6 | 160.4 | 13.5395212 | 1443.6 | 121.855631 |
| 7 | 20.2 | 1.7051016 | 181.8 | 15.3459162 |

* TURNING CELL TIME

| LATHE 1 | LATHE 2 | WASHER | MINI-MOVER-5 |
|---|---|---|---|
| .512307909 | .241162028 | .150608886 | .7842 |

* DECISION RULE SET=SPT/WINQ
* TIME SCALING FACTOR= 11.6828

| PART | ORIGINAL PROCESSING TIME | ADJUSTED PROCESSING TIME | ORIGINAL DUE-DATE | ADJUSTED DUE-DATE |
|---|---|---|---|---|
| 1 | 47.8 | 4.0914489 | 610.2 | 52.2301828 |
| 2 | 82.8 | 7.08728142 | 745.2 | 63.7855327 |
| 3 | 23 | 1.96868928 | 387 | 33.125337 |
| 4 | 11.2 | .958666085 | 100.8 | 8.62798476 |
| 5 | 14.4 | 1.23257068 | 309.6 | 26.5002686 |
| 6 | 160.4 | 13.7294679 | 1443.6 | 123.565211 |
| 7 | 20.2 | 1.72902276 | 181.8 | 15.5612048 |

* TURNING CELL TIME

| LATHE 1 | LATHE 2 | WASHER | MINI-MOVER-5 |
|---|---|---|---|
| .525729693 | .247418583 | .15455544 | .7842 |

* DECISION RULE SET=DDATE/RANDOM
* TIME SCALING FACTOR=  11.8578

| PART | ORIGINAL PROCESSING TIME | ADJUSTED PROCESSING TIME | ORIGINAL DUE-DATE | ADJUSTED DUE-DATE |
|---|---|---|---|---|
| 1 | 47.8 | 4.03116989 | 610.2 | 51.4606666 |
| 2 | 82.8 | 6.98280332 | 745.2 | 62.8457698 |
| 3 | 23 | 1.93968425 | 387 | 32.6372953 |
| 4 | 11.2 | .944541687 | 100.8 | 8.50087708 |
| 5 | 14.4 | 1.21441101 | 309.6 | 26.1098388 |
| 6 | 160.4 | 13.5271693 | 1443.6 | 121.744704 |
| 7 | 20.2 | 1.70354878 | 181.8 | 15.331939 |

* TURNING CELL TIME

| LATHE 1 | LATHE 2 | WASHER | MINI-MOVER-5 |
|---|---|---|---|
| .511438586 | .248881839 | .158353484 | .7842 |

* DECISION RULE SET=DDATE/FMFS
* TIME SCALING FACTOR=  11.9675

| PART | ORIGINAL PROCESSING TIME | ADJUSTED PROCESSING TIME | ORIGINAL DUE-DATE | ADJUSTED DUE-DATE |
|---|---|---|---|---|
| 1 | 47.8 | 3.99415683 | 610.2 | 50.9880928 |
| 2 | 82.8 | 6.91873825 | 745.2 | 62.2686442 |
| 3 | 23 | 1.92187174 | 387 | 32.337581 |
| 4 | 11.2 | .935867876 | 100.8 | 8.42281179 |
| 5 | 14.4 | 1.20325883 | 309.6 | 25.8700648 |
| 6 | 160.4 | 13.4028664 | 1443.6 | 120.626687 |
| 7 | 20.2 | 1.68790474 | 181.8 | 15.1911427 |

* TURNING CELL TIME

| LATHE 1 | LATHE 2 | WASHER | MINI-MOVER-5 |
|---|---|---|---|
| .502658827 | .236560983 | .147773003 | .7842 |

* DECISION RULE SET=DDATE/NINQ
* TIME SCALING FACTOR= 11.7589

| PART | ORIGINAL PROCESSING TIME | ADJUSTED PROCESSING TIME | ORIGINAL DUE-DATE | ADJUSTED DUE-DATE |
|---|---|---|---|---|
| 1 | 47.8 | 4.06500608 | 610.2 | 51.892609 |
| 2 | 82.8 | 7.04147498 | 745.2 | 63.3732747 |
| 3 | 23 | 1.95596527 | 387 | 32.9112417 |
| 4 | 11.2 | .952470643 | 100.8 | 8.57223039 |
| 5 | 14.4 | 1.22460434 | 309.6 | 26.3289934 |
| 6 | 160.4 | 13.6407317 | 1443.6 | 122.766585 |
| 7 | 20.2 | 1.71784776 | 181.8 | 15.4606288 |

* TURNING CELL TIME

| LATHE 1 | LATHE 2 | WASHER | MINI-MOVER-5 |
|---|---|---|---|
| .518458527 | .244487716 | .152712118 | .7842 |

* DECISION RULE SET=DDATE/WINQ
* TIME SCALING FACTOR= 11.6064

| PART | ORIGINAL PROCESSING TIME | ADJUSTED PROCESSING TIME | ORIGINAL DUE-DATE | ADJUSTED DUE-DATE |
|---|---|---|---|---|
| 1 | 47.8 | 4.11841743 | 610.2 | 52.5744417 |
| 2 | 82.8 | 7.13389583 | 745.2 | 64.2059553 |
| 3 | 23 | 1.98166529 | 387 | 33.3436725 |
| 4 | 11.2 | .964984835 | 100.8 | 8.68486353 |
| 5 | 14.4 | 1.24069478 | 309.6 | 26.674838 |
| 6 | 160.4 | 13.8198614 | 1443.6 | 124.379653 |
| 7 | 20.2 | 1.74041896 | 181.8 | 15.6637717 |

* TURNING CELL TIME

| LATHE 1 | LATHE 2 | WASHER | MINI-MOVER-5 |
|---|---|---|---|
| .53212405 | .250427882 | .156435269 | .7842 |

* DECISION RULE SET=SLACK/RANDOM
* TIME SCALING FACTOR= 11.6784

| PART | ORIGINAL PROCESSING TIME | ADJUSTED PROCESSING TIME | ORIGINAL DUE-DATE | ADJUSTED DUE-DATE |
|---|---|---|---|---|
| 1 | 47.8 | 4.09302644 | 610.2 | 52.2503083 |
| 2 | 82.8 | 7.09001233 | 745.2 | 63.810111 |
| 3 | 23 | 1.96944787 | 387 | 33.1381011 |
| 4 | 11.2 | .959035484 | 100.8 | 8.63131936 |
| 5 | 14.4 | 1.23304562 | 309.6 | 26.5104808 |
| 6 | 160.4 | 13.7347582 | 1443.6 | 123.612824 |
| 7 | 20.2 | 1.729683 | 181.8 | 15.567201 |

* TURNING CELL TIME

| LATHE 1 | LATHE 2 | WASHER | MINI-MOVER-5 |
|---|---|---|---|
| .526103518 | .247594509 | .154665336 | .7842 |

* DECISION RULE SET=SLACK/FMFS
* TIME SCALING FACTOR= 11.7574

| PART | ORIGINAL PROCESSING TIME | ADJUSTED PROCESSING TIME | ORIGINAL DUE-DATE | ADJUSTED DUE-DATE |
|---|---|---|---|---|
| 1 | 47.8 | 4.06552469 | 610.2 | 51.8992284 |
| 2 | 82.8 | 7.04237331 | 745.2 | 63.3813588 |
| 3 | 23 | 1.95621481 | 387 | 32.9154405 |
| 4 | 11.2 | .952591559 | 100.8 | 8.57332403 |
| 5 | 14.4 | 1.22476058 | 308.6 | 26.3323524 |
| 6 | 160.4 | 13.642472 | 1443.6 | 122.782248 |
| 7 | 20.2 | 1.71806692 | 181.8 | 15.4626023 |

* TURNING CELL TIME

| LATHE 1 | LATHE 2 | WASHER | MINI-MOVER-5 |
|---|---|---|---|
| .519582498 | .24452559 | .152748269 | .7842 |

* DECISION RULE SET=SLACK/NINQ
* TIME SCALING FACTOR= 11.559

| PART | ORIGINAL PROCESSING TIME | ADJUSTED PROCESSING TIME | ORIGINAL DUE-DATE | ADJUSTED DUE-DATE |
|---|---|---|---|---|
| 1 | 47.8 | 4.12104492 | 610.2 | 52.6679835 |
| 2 | 82.8 | 7.13654643 | 745.2 | 64.2468179 |
| 3 | 23 | 1.98292956 | 387 | 33.3849453 |
| 4 | 11.2 | .865600483 | 100.8 | 8.69040435 |
| 5 | 14.4 | 1.24148634 | 309.6 | 26.6918562 |
| 6 | 160.4 | 13.8287763 | 1443.6 | 124.453005 |
| 7 | 20.2 | 1.74152944 | 181.8 | 15.673765 |

* TURNING CELL TIME

| LATHE 1 | LATHE 2 | WASHER | MINI-MOVER-5 |
|---|---|---|---|
| .532747063 | .25072100 | .156018424 | .7842 |

* DECISION RULE SET=SLACK/WINQ
* TIME SCALING FACTOR= 11.6528

| PART | ORIGINAL PROCESSING TIME | ADJUSTED PROCESSING TIME | ORIGINAL DUE-DATE | ADJUSTED DUE-DATE |
|---|---|---|---|---|
| 1 | 47.8 | 4.1620184 | 610.2 | 52.3850886 |
| 2 | 82.8 | 7.10558836 | 745.2 | 63.8502852 |
| 3 | 23 | 1.97377455 | 387 | 33.2108021 |
| 4 | 11.2 | .861142387 | 100.8 | 8.65028148 |
| 5 | 14.4 | 1.2357545 | 309.6 | 26.5687217 |
| 6 | 160.4 | 13.764932 | 1443.6 | 123.884338 |
| 7 | 20.2 | 1.73348895 | 181.8 | 15.6014005 |

* TURNING CELL TIME

| LATHE 1 | LATHE 2 | WASHER | MINI-MOVER-5 |
|---|---|---|---|
| .528235629 | .248597922 | .15529214 | .7842 |

* DECISION RULE SET=S/PT/RANDOM
* TIME SCALING FACTOR= 11.7927

| PART | ORIGINAL PROCESSING TIME | ADJUSTED PROCESSING TIME | ORIGINAL DUE-DATE | ADJUSTED DUE-DATE |
|---|---|---|---|---|
| 1 | 47.8 | 4.05335504 | 610.2 | 51.7438755 |
| 2 | 82.8 | 7.02128284 | 745.2 | 63.1918355 |
| 3 | 23 | 1.95035912 | 387 | 32.8169122 |
| 4 | 11.2 | .948740083 | 100.8 | 8.54766084 |
| 5 | 14.4 | 1.22108441 | 308.6 | 26.2535297 |
| 6 | 160.4 | 13.6016349 | 1443.6 | 122.414714 |
| 7 | 20.2 | 1.7129241 | 181.8 | 15.4163169 |

* TURNING CELL TIME

| LATHE 1 | LATHE 2 | WASHER | MINI-MOVER-5 |
|---|---|---|---|
| .516696815 | .243167578 | .151698858 | .7842 |

* DECISION RULE SET=S/PT/FMFS
* TIME SCALING FACTOR= 11.9217

| PART | ORIGINAL PROCESSING TIME | ADJUSTED PROCESSING TIME | ORIGINAL DUE-DATE | ADJUSTED DUE-DATE |
|---|---|---|---|---|
| 1 | 47.8 | 4.00948529 | 610.2 | 51.1838755 |
| 2 | 82.8 | 6.9453182 | 745.2 | 62.5078638 |
| 3 | 23 | 1.92925506 | 387 | 32.4618133 |
| 4 | 11.2 | .938463331 | 100.8 | 8.45516388 |
| 5 | 14.4 | 1.20788143 | 308.6 | 25.8684507 |
| 6 | 160.4 | 13.454457 | 1443.6 | 121.080113 |
| 7 | 20.2 | 1.68438822 | 181.8 | 15.249503 |

* TURNING CELL TIME

| LATHE 1 | LATHE 2 | WASHER | MINI-MOVER-5 |
|---|---|---|---|
| .508297199 | .238273272 | .148842621 | .7842 |

* DECISION RULE SET=S/PT/NINQ
* TIME SCALING FACTOR= 11.6739

| PART | ORIGINAL PROCESSING TIME | ADJUSTED PROCESSING TIME | ORIGINAL DUE-DATE | ADJUSTED DUE-DATE |
|---|---|---|---|---|
| 1 | 47.8 | 4.0946042 | 610.2 | 52.2704495 |
| 2 | 82.8 | 7.09274536 | 745.2 | 63.8347032 |
| 3 | 23 | 1.97020704 | 387 | 33.150875 |
| 4 | 11.2 | .959405169 | 100.8 | 8.63464653 |
| 5 | 14.4 | 1.23352093 | 309.6 | 26.5207 |
| 6 | 160.4 | 13.7400526 | 1443.6 | 123.660473 |
| 7 | 20.2 | 1.73035575 | 181.8 | 15.5732016 |

* TURNING CELL TIME

| LATHE 1 | LATHE 2 | WASHER | MINI-MOVER-5 |
|---|---|---|---|
| .526477626 | .247770572 | .154775316 | .7842 |

* DECISION RULE SET=S/PT/WINQ
* TIME SCALING FACTOR= 11.4768

| PART | ORIGINAL PROCESSING TIME | ADJUSTED PROCESSING TIME | ORIGINAL DUE-DATE | ADJUSTED DUE-DATE |
|---|---|---|---|---|
| 1 | 47.8 | 4.16492402 | 610.2 | 53.1681305 |
| 2 | 82.8 | 7.21455459 | 745.2 | 64.9308313 |
| 3 | 23 | 2.00404294 | 387 | 33.7202006 |
| 4 | 11.2 | .975881778 | 100.8 | 8.78293601 |
| 5 | 14.4 | 1.25470514 | 309.6 | 26.9761606 |
| 6 | 160.4 | 13.9760212 | 1443.6 | 125.784191 |
| 7 | 20.2 | 1.76007249 | 181.8 | 15.8406525 |

* TURNING CELL TIME

| LATHE 1 | LATHE 2 | WASHER | MINI-MOVER-5 |
|---|---|---|---|
| .543151367 | .255617557 | .158677105 | .7842 |

* DECISION RULE SET=VALUE/RANDOM
* TIME SCALING FACTOR= 12.1102

| PART | ORIGINAL PROCESSING TIME | ADJUSTED PROCESSING TIME | ORIGINAL DUE-DATE | ADJUSTED DUE-DATE |
|---|---|---|---|---|
| 1 | 47.8 | 3.94708593 | 610.2 | 50.3872768 |
| 2 | 82.8 | 6.83721181 | 745.2 | 61.5349045 |
| 3 | 23 | 1.89922545 | 387 | 31.9565325 |
| 4 | 11.2 | .924840217 | 100.8 | 8.32356196 |
| 5 | 14.4 | 1.18908026 | 309.6 | 25.565226 |
| 6 | 160.4 | 13.2450331 | 1443.6 | 119.205298 |
| 7 | 20.2 | 1.66801539 | 181.8 | 15.0121385 |

* TURNING CELL TIME

| LATHE 1 | LATHE 2 | WASHER | MINI-MOVER-5 |
|---|---|---|---|
| .49149913 | .231209013 | .144482245 | .7842 |

* DECISION RULE SET=VALUE/FMFS
* TIME SCALING FACTOR= 12.1869

| PART | ORIGINAL PROCESSING TIME | ADJUSTED PROCESSING TIME | ORIGINAL DUE-DATE | ADJUSTED DUE-DATE |
|---|---|---|---|---|
| 1 | 47.8 | 3.82224438 | 610.2 | 50.0701573 |
| 2 | 82.8 | 6.78418064 | 745.2 | 61.1476258 |
| 3 | 23 | 1.8872724 | 387 | 31.7554095 |
| 4 | 11.2 | .919018683 | 100.8 | 8.27117643 |
| 5 | 14.4 | 1.18159863 | 309.6 | 25.4043276 |
| 6 | 160.4 | 13.1616736 | 1443.6 | 118.455062 |
| 7 | 20.2 | 1.6575175 | 181.8 | 14.9176575 |

* TURNING CELL TIME

| LATHE 1 | LATHE 2 | WASHER | MINI-MOVER-5 |
|---|---|---|---|
| .485608876 | .228536946 | .142760612 | .7842 |

* DECISION RULE SET=VALUE/NINQ
* TIME SCALING FACTOR= 11.8951

| PART | ORIGINAL PROCESSING TIME | ADJUSTED PROCESSING TIME | ORIGINAL DUE-DATE | ADJUSTED DUE-DATE |
|---|---|---|---|---|
| 1 | 47.8 | 4.01848138 | 610.2 | 51.2984338 |
| 2 | 82.8 | 6.96084943 | 745.2 | 62.6478449 |
| 3 | 23 | 1.93358929 | 387 | 32.5344049 |
| 4 | 11.2 | .941584174 | 100.8 | 8.47407756 |
| 5 | 14.4 | 1.21058251 | 309.6 | 26.027524 |
| 6 | 160.4 | 13.4845441 | 1443.6 | 121.360897 |
| 7 | 20.2 | 1.69817824 | 181.8 | 15.2836042 |

* TURNING CELL TIME

| LATHE 1 | LATHE 2 | WASHER | MINI-MOVER-5 |
|---|---|---|---|
| .508423178 | .238273788 | .149467622 | .7842 |

* DECISION RULE SET=VALUE/WINQ
* TIME SCALING FACTOR= 11.736

| PART | ORIGINAL PROCESSING TIME | ADJUSTED PROCESSING TIME | ORIGINAL DUE-DATE | ADJUSTED DUE-DATE |
|---|---|---|---|---|
| 1 | 47.8 | 4.07293797 | 610.2 | 51.993865 |
| 2 | 82.8 | 7.05521473 | 745.2 | 63.4969325 |
| 3 | 23 | 1.95978187 | 387 | 32.9754601 |
| 4 | 11.2 | .954328562 | 100.8 | 8.58895706 |
| 5 | 14.4 | 1.22699387 | 309.6 | 26.3803681 |
| 6 | 160.4 | 13.6673483 | 1443.6 | 123.006135 |
| 7 | 20.2 | 1.72119973 | 181.8 | 15.4907976 |

* TURNING CELL TIME

| LATHE 1 | LATHE 2 | WASHER | MINI-MOVER-5 |
|---|---|---|---|
| .521340281 | .245352838 | .153285027 | .7842 |

# XIV. APPENDIX C: FAILURE DATA ANALYSIS

## A. Raw Data

The purpose of this appendix is to describe the procedure of determination of the MTBF, MDT and availability for the major system components.

Failure data obtained from the actual system were as follows:

- Total downtimes in hours and total number of failures of five AS/RS carts over 19 days with two shifts/day;
- Total downtimes in hours and total number of failures of four different robots over 365 days;
- Total downtimes in hours for four machine centers over 72 days.

The failure data of both the AS/RS carts and the robots were obtained from a second midwestern manufacturing facility. This is because the data from the first manufacturing facility with the actual FMS were not available during completion of this research. This first facility provided only failure data for four machine centers.

Specific analysis of each set of actual data is described in the following sections.

## B. Analysis of the AS/RS Cart's Failure Data

Actual failure data obtained for the AS/RS carts consisted of total downtimes and total number of failures of five carts over 19 days with two shifts per day. The total available production time for the five carts over 19 days was 1,520 hours (19 days * 8 hours/shift * 2 shifts/day * 5 carts).

Actual raw data can be classified by shifts over 19 days as follows:

. First shift:

total downtime of five carts = 100.2 hours
total number of failures of five carts = 440 times;

. Second shift:

total downtime of five carts = 53.5333 hours,
total number of failures of five carts = 398 times.

From these data, the MTBF, MDT and availability of all five carts were computed as follows:

$$. \ MDT = \frac{\text{total downtime}}{\text{total number of failures}} = \frac{100.2 + 53.5333}{440 + 398}$$

$$= 0.1835 \text{ (hours)};$$

$$. \ \text{Availability} = \frac{\text{total uptime}}{\text{total available production time}}$$

$$= \frac{1520 - (100.2 + 53.5333)}{1520} = 0.8989$$

$$= \frac{MTBF}{MTBF + MDT} \qquad (14\text{-}1)$$

$$. \ MTBF = \frac{(\text{availability}) * MDT}{1 - \text{availability}} \qquad \text{(from Equation 14-1)}$$

$$= 1.6315 \text{ (hours)}.$$

Because the FMS model operated with only one AS/RS cart, the MDT, MTBF, and availability obtained from five AS/RS carts were used for the model's AS/RS cart.

Using the MTBF, random numbers for uptimes between failures were generated from an exponential random number generator. This procedure was described in Chapter 5.

## C. Analysis of the Robot's Failure Data

Actual failure data obtained for four independent robots were total downtimes and total number of failures of four robots over 365 days. Also, the availability of each robot was available for this research.

The actual data were as follows:

- Total downtime of four robots = 1,118.31 hours;
- Total number of failures of four robots = 358 times;
- Availability of robot 1 = 0.9637;
- Availability of robot 2 = 0.9731;
- Availability of robot 3 = 0.9671;
- Availability of robot 4 = 0.9434.

From these data, the MTBF, MDT and availability of all four robots were computed as follows:

$$\text{. MDT} = \frac{\text{total down times}}{\text{total number of failures}} = \frac{1118.31}{358}$$

$$= 3.1238 \text{ (hours);}$$

$$\text{. Availability} = \frac{0.9637 + 0.9731 + 0.9671 + 0.9434}{4}$$

$$= 0.9618$$

$$\text{. MTBF} = \frac{\text{(availability)} * \text{MDT}}{1 - \text{availability}} \quad \text{(from Equation 14-1)}$$

$$= 78.6511 \text{ (hours).}$$

The turning cell of the model has only one miniature robot (the Mini-Mover-5). Therefore, the MDT, MTBF and availability obtained from four independent robots were used for the model's robot. Using the MTBF, random numbers for uptime between failures were generated from an exponential random number generator. This procedure was described in Chapter 5.

D. Analysis of the Machine Center Cell's Failure Data

Actual failure data obtained for the machine center cell consisted of total downtime for four machine centers over 72 days. The total number of failures for the four machine centers was not available in the actual data. As described previously, the total number of failures was a main factor in determining the MDT, MTBF and availability of a component. Since the total number of failures was not available, the MDT, and MTBF were estimated using a Poisson process.

The FMS model has six identical machine centers which can fail equally likelyhood. The failure parameters (MDT, MTBF and availability) for the fifth and sixth machine centers were estimated from the obtained failure data. A detailed description of the procedure used is presented in this section.

The total available production time for each of the four machine centers over 72 days was 1,440 hours (72 days * 20 hours/day).

## 1. Actual failure data

This estimation process was necessary to estimate the failure data for the six machine centers in the model. The process was necessary because the actual data was not sufficient to accurately specify the mean time between failures (MTBF) and the mean downtime (MDT). The actual data showed the total failure time of each of four actual machine centers on an irregular time interval. The obtained actual failure data for the four machine centers is presented in Table 14-1. From the data in Table 14-1, the total downtime for each machine center can summarized as shown in Table 14-2.

## 2. Poisson process

A stochastic process (N(t), t >= 0) is said to be a counting process if N(t) represents the total number of "events" that have occurred up to time t (37). One of the most important types of counting process is the Poisson process which is defined as follows (37).

definition: The counting process (N(t), t>=0) is said to be a Poisson process having rate $\lambda$ , $\lambda$ >0 if

i) N(0)= 0.

ii) the process has independent increments;

iii) the number of events in any interval of length t is Poisson distributed with mean t. That is, for all s, t>=0,

$$P((N(t+s) - N(t))= n)= EXP(-\lambda t) * (\lambda t)^n /n!$$

n=0, 1, 2, ----.

Table 14-1. Raw failure data for four machine centers

| A | B | C | D | A | B | C | D |
|---|---|---|---|---|---|---|---|
| 1 | 320 | 1 | 80.0 | 8 | 80 | 1 | 4.8 |
| | | 2 | 41.6 | | | 2 | 0.0 |
| | | 3 | 22.4 | | | 3 | 0.0 |
| | | 4 | 0.0 | | | 4 | 0.0 |
| 2 | 208 | 1 | 14.5 | 9 | 80 | 1 | 0.0 |
| | | 2 | 10.4 | | | 2 | 0.8 |
| | | 3 | 76.9 | | | 3 | 0.0 |
| | | 4 | 6.2 | | | 4 | 0.0 |
| 3 | 80 | 1 | 0.0 | 10 | 64 | 1 | 0.6 |
| | | 2 | 1.6 | | | 2 | 0.0 |
| | | 3 | 0.0 | | | 3 | 0.0 |
| | | 4 | 1.6 | | | 4 | 0.0 |
| 4 | 80 | 1 | 4.8 | 11 | 80 | 1 | 0.0 |
| | | 2 | 7.2 | | | 2 | 0.0 |
| | | 3 | 0.0 | | | 3 | 0.0 |
| | | 4 | 0.0 | | | 4 | 0.0 |
| 5 | 64 | 1 | 1.3 | 12 | 80 | 1 | 8.0 |
| | | 2 | 3.81 | | | 2 | 5.6 |
| | | 3 | 0.0 | | | 3 | 58.4 |
| | | 4 | 4.5 | | | 4 | 4.8 |
| 6 | 80 | 1 | 6.4 | 13 | 80 | 1 | 0.0 |
| | | 2 | 8.0 | | | 2 | 32.0 |
| | | 3 | 0.0 | | | 3 | 4.0 |
| | | 4 | 8.0 | | | 4 | 0.0 |
| 7 | 64 | 1 | 2.6 | 14 | 80 | 1 | 1.6 |
| | | 2 | 8.3 | | | 2 | 0.0 |
| | | 3 | 1.6 | | | 3 | 9.6 |
| | | 4 | 0.0 | | | 4 | 0.8 |

A = time interval

B = duration (hrs.)

C = machine centers 1 through 4

D = total downtime (hrs.)

Table 14-2. Total downtimes for each machine center

| Machine center | Total downtime (hr.) | Total data collection time (hr.) |
|---|---|---|
| 1 | 124.6 | 1,440 |
| 2 | 119.3 | 1,440 |
| 3 | 172.9 | 1,440 |
| 4 | 25.9 | 1,440 |

Note that it follows from condition (iii) that a Poisson process has stationary increments and also that

$$E(N(t)) = \lambda \cdot t \qquad (14\text{-}2)$$

which explains why $\lambda$ is called the rate of the process.

## 3. Use of Poisson process

To estimate the number of failures at time t, the following processes were used.

- Assumption: Failures of each machine center occur at time t according to a Poisson process.
- Parameters: $\lambda$ = mean failure rate

  $\frac{1}{\lambda}$ = mean time between failures
- Variables: $X(i) = 1$ if at least one failure occurs in the i th period (time interval),

  $= 0$ otherwise (i=1, 2, ---, 14).

  $t(i)$ = actual operation time of i th period (total available manufacturing time total down time of i th period).

Then, by the definition of the Poisson process,

$$P(X(i)=0) = P(\text{no failure occurrences in period } t(i)) = EXP(-\lambda\, t(i)) \qquad (14\text{-}3)$$

$$P(X(i)=1) = P(1 \text{ or more failures in period } t(i)) = 1 - EXP(-\lambda\, t(i)) \qquad (14\text{-}4)$$

With both Equations 14-3 and 14-4, the following joint probability functions can be established for each machine center. For example, machine center 1 has one or more failures at time intervals 1, 2, 4, 5, 6, 7, 8, 10, 12 and 14 in Table 14-1. In time intervals 3, 9, 11 and 13, there were no failures in machine center 1. The same procedure is applied to other machine centers. As a result, the following joint probability functions can be established.

. machine center 1

$$P(X(1)=X(2)=1,\ X(3)=0,\ X(4)=X(5)=X(6)=X(7)=X(8)=1,\ X(9)=0,\ X(10)=1,\ X(11)=0,\ X(12)=1,\ X(13)=0,\ X(14)=1 : \frac{1}{\lambda}) \quad (14\text{-}5)$$

$$= (1 - EXP(-240\lambda))(1 - EXP(-193.5\lambda))(EXP(-80\lambda))(EXP(-64\lambda))(1 - EXP(-75.2\lambda))(1 - EXP(-62.7\lambda))(1 - EXP(-61.4\lambda))(1 - EXP(-75.2\lambda))(1 - EXP(-63.4\lambda))(1 - EXP(-72\lambda))(1 - EXP(-78.4\lambda))$$

$$= (1 - EXP(-240\lambda))(1 - EXP(-193.5\lambda))(EXP(-368\lambda))(1 - EXP(-75.2\lambda))(1 - EXP(-62.7\lambda))(1 - EXP(-61.4\lambda))(1 - EXP(-63.4\lambda))(1 - EXP(-72\lambda))(1 - EXP(-78.4\lambda))$$

. machine center 2

$$P(X(1)=X(2)=X(3)=X(4)=X(5)=X(6)=X(7)=1,\ X(5)=X(6)=X(7)=X(8)=0,\ X(9)=1,\ X(10)=X(11)=0,\ X(12)=X(13)=1,\ X(14)=0 : \frac{1}{\lambda}) \quad (14\text{-}6)$$

$$= (1 - EXP(-278.4\lambda))(1 - EXP(-197.6\lambda))(1 - EXP(-78.4\lambda))(1 - EXP(-72.8\lambda))(1 - EXP(-60.19\lambda))(1 - EXP(-72\lambda))(1 - EXP(-55.7\lambda))(EXP(-80\lambda))(1 - EXP(-79.2\lambda))(EXP(-64\lambda))(1 - EXP(-74.4\lambda))(1 - EXP(-48\lambda))$$

$$= (1 - EXP(-278.4\lambda))(1 - EXP(-197.6\lambda))(1 - EXP(-78.4\lambda))(1 - EXP(-72.8\lambda))(1 - EXP(-60.19\lambda))(1 - EXP(-72\lambda))(1 - EXP(-55.7\lambda))(EXP(-304\lambda))(1 - EXP(-79.2\lambda))(1 - EXP(-74.4\lambda))(1 - EXP(-48\lambda))$$

. machine center 3

$$P(X(1)=X(2)=1,\ X(3)=X(4)=X(5)=X(6)=0,\ X(8)=X(9)=X(10)=X(11)=0,\ X(12)=X(13)=X(14)=1 : \frac{1}{\lambda}) \qquad (14\text{-}7)$$

$$= (1 - EXP(-297.6\lambda))(1 - EXP(-131.1\lambda))(EXP(-80\lambda))(1 - EXP(-62.4\lambda))(EXP(-64\lambda))(1 - EXP(-21.6\lambda))(1 - EXP(-76\lambda))(1 - EXP(-70.4\lambda))$$

$$= (1 - EXP(-297.6\lambda))(1 - EXP(-131.1\lambda))(EXP(-608\lambda))(1 - EXP(-62.4\lambda))(1 - EXP(-21.6\lambda))(1 - EXP(-76\lambda))(1 - EXP(-70.4\lambda))$$

. machine center 4

$$P(X(1)=0,\ X(2)=X(3)=1,\ X(4)=0,\ X(5)=X(6)=1,\ X(7)=X(8)=X(9)=X(10)=X(11)=0,\ X(12)=1,\ X(13)=0,\ X(14)=1 : \frac{1}{\lambda}) \qquad (14\text{-}8)$$

$$= (1 - EXP(-320\lambda))(1 - EXP(-201.8\lambda))(1 - EXP(-78.4\lambda))(EXP(-80\lambda))(1 - EXP(-59.5\lambda))(1 - EXP(-72\lambda))(EXP(-64\lambda))(1 - EXP(-75.2\lambda))(1 - EXP(-79.2\lambda))$$

## 4. Use of the maximum likelihood method

To estimate $\lambda$, the maximum likelihood method (32) is adopted. The maximum likelihood method is a method by which the unknown population parameter can be estimated with the values of a random sample. The maximum likelihood estimator is the value for which the probability of obtaining the observed data is a maximum.

The likelihood function is defined as follows.

definition: If $x_1$, $x_2$, ---, and $x_n$ are the values of a random sample from a population with the parameter $\theta$, the likelihood function of the sample is given by

$$L(\theta) = f(x_1, x_2, ---, x_n : \theta)$$

for values of within a given domain. Here $f(x_1, x_2, ---, x_n : \theta)$ is the value of the joint density function of the random variables $X_1$, $X_2$, ---, $X_n$ at the observed sample point.

Thus, the method of maximum likelihood consists of maximizing the likelihood function with respect to $\theta$. The value of $\theta$ that maximize the likelihood function is the maximum likelihood estimator of $\theta$.

An example application of the maximum likelihood method to the joint probability function of machine center 3 is shown. The solution procedures for the other machine centers are the same as that of machine center 3.

. machine center 3

$$L(\frac{1}{\lambda}) = (1 - EXP(-297.6\lambda))(1 - EXP(-131.1\lambda))(EXP(-608\lambda))(1 - EXP(-62.4\lambda))(1 - EXP(-21.6\lambda))(1 - EXP(-76\lambda))(1 - EXP(-70.4\lambda)) \quad (14\text{-}9)$$

$$\ln L(\frac{1}{\lambda}) = \ln(1 - EXP(-297.6\lambda)) + \ln(1 - EXP(-131.1\lambda)) + \ln(EXP(-608\lambda)) + \ln(1 - EXP(-62.4\lambda)) + \ln(1 - EXP(-21.6\lambda)) + \ln(1 - EXP(-76\lambda)) + \ln(1 - EXP(-70.4\lambda)) \quad (14\text{-}10)$$

To maximize $\ln L(\frac{1}{\lambda})$, the first derivative is taken both sides.

$$\frac{\partial(\ln(L(\frac{1}{\lambda})))}{\partial\lambda} = \frac{297.6 * (EXP(-297.6\lambda))}{(1 - EXP(-297.6\lambda))} + \frac{131.1 * (EXP(-131.1\lambda))}{(1 - EXP(-131.1\lambda))} + \frac{62.4 * (EXP(-62.4\lambda))}{(1 - EXP(-62.4\lambda))} + \frac{21.6 * (EXP(-21.6\lambda))}{(1 - EXP(-21.6\lambda))} + \frac{76 * (EXP(-76\lambda))}{(1 - EXP(-76\lambda))} + \frac{70.4 * (EXP(-70.4\lambda))}{(1 - EXP(-70.4\lambda))} - 608 = 0. \quad (14\text{-}11)$$

This complex equation was solved by a TRS-80 Model III micro-computer. $\lambda$ was found to be 0.0069. $\frac{1}{\lambda}$ is thus 145.2707. This means that the mean failure rate per hour was 0.0069 and the mean time between failures (MTBF) is 145.2707 hours. With these MTBF values, random numbers for uptimes between failures of each machine center were generated by an exponential random number generator. This procedure was described in Chapter 5.

### 5. Generating failure data of machine centers

Utilizing the Poisson process and the method of maximum likelihood, the MTBF of each machine center was obtained. The original failure data obtained from the actual system contained only total downtimes of four machine centers. The physical model had six identical machine centers. Two additional MTBF values were therefore derived from the MTBF values of four machine centers. The MTBF value for machine centers 5 and 6 was the average value of the MTBF values of machine centers 1, 2, 3 and 4. These MTBF values used to generate random uptimes between failures for machine centers 5 and 6. This procedure was described in Chapter 5.

The mean downtime of a machine center was estimated by the following equation.

$$\frac{MDT(i)}{MTBF(i) + MDT(i)} = \frac{TDT(i)}{TT} \qquad (14\text{-}12)$$

Then,

$$MDT(i) = \frac{TDT(i) + MTBF(i)}{TT - TDT(i)}$$

where

MDT(i) = the mean downtime of machine center i;
MTBF(i) = the mean between failures of machine center i;
TDT(i) = the total downtime of machine center i;
TT = the total data collection time (= 1,440 hours);
i = an index for a machine center (i= 1, 2, ---, 6).

The righthand side of Equation 14-12 is equivalent to (1 - availability). The availability was determined by MTBF/(MTBF + MDT).

The average MDT value of machine centers 1, 2, 3 and 4 was used as the MDT values for machine centers 5 and 6. The estimated failure data for six machine centers are as follows.

Table 14-3. Estimated failure data

| Machine center | MTBF (hrs.) | MDT (hrs.) | Availability |
|---|---|---|---|
| 1 | 66.7697 | 6.3225 | 0.9135 |
| 2 | 64.1815 | 5.7971 | 0.9172 |
| 3 | 145.2707 | 19.8283 | 0.8799 |
| 4 | 183.4626 | 3.3628 | 0.9820 |
| 5 | 114.9211 | 8.8277 | 0.9287 |
| 6 | 114.9211 | 8.8277 | 0.9287 |

# XV. APPENDIX D: FAILURE DATA AND SIMULATION TIMES

The following data present the failure data for major system components, and simulation times for twenty-eight decision rule sets. The reader should be noted the following points:

- . All actual times are in minutes;
- . Adjusted times are actual times reduced by the applicable time scaling factor;
- . All adjusted times are in minutes.

DECISION RULƎ ƎET= RANDOM/RANDOM
TIME SCALING FACTOR= 12.2087 ; SIMULATION TIME= 688.146873

| NO. | FAILED COMPONENT | ACTUAL FAILING TIME | ACTUAL RECOVERY TIME | ADJUSTED FAILING TIME | ADJUSTED RECOVERY TIME |
|---|---|---|---|---|---|
| 1 | AS/RS CART | 75.744 | 86.754 | 6.20511887 | 7.10708054 |
| 2 | AS/RS CART | 151.29 | 162.3 | 12.3940131 | 13.2959788 |
| 3 | AS/RS CART | 188.91 | 199.92 | 15.4759272 | 16.3778908 |
| 4 | AS/RS CART | 387.06 | 398.07 | 31.7088157 | 32.6107793 |
| 5 | MINI-MOVER-5 | 567.336 | 754.764 | 46.4774263 | 61.8319448 |
| 6 | AS/RS CART | 810.838 | 821.848 | 66.4091032 | 67.3110669 |
| 7 | AS/RS CART | 931.674 | 942.684 | 76.3248053 | 77.2267683 |
| 8 | AS/RS CART | 994.56 | 1005.57 | 81.4765661 | 82.3785298 |
| 9 | MACHINE CENTER 4 | 1038.47 | 1240.238 | 85.073771 | 101.603054 |
| 10 | AS/RS CART | 1133.85 | 1144.86 | 92.8957048 | 93.7976685 |
| 11 | AS/RS CART | 1255.38 | 1266.37 | 102.841882 | 103.743846 |
| 12 | AS/RS CART | 1292.76 | 1303.77 | 105.905773 | 106.807737 |
| 13 | AS/RS CART | 1344.59 | 1355.6 | 110.151802 | 111.053766 |
| 14 | AS/RS CART | 1386.1 | 1397.11 | 113.552393 | 114.454357 |
| 15 | AS/RS CART | 1551.55 | 1562.56 | 127.106425 | 128.008389 |
| 16 | AS/RS CART | 1720.57 | 1731.58 | 140.952919 | 141.854883 |
| 17 | AS/RS CART | 1822.37 | 1833.38 | 149.292602 | 150.194565 |
| 18 | AS/RS CART | 1914.59 | 1925.6 | 156.847469 | 157.749433 |
| 19 | AS/RS CART | 2005.86 | 2016.89 | 164.334341 | 165.236305 |
| 20 | AS/RS CART | 2111.21 | 2122.22 | 172.955017 | 173.85698 |
| 21 | AS/RS CART | 2283.37 | 2294.38 | 187.058746 | 187.96071 |
| 22 | AS/RS CART | 2561.25 | 2572.26 | 209.823294 | 210.725258 |
| 23 | AS/RS CART | 2689.37 | 2700.38 | 220.319169 | 221.221133 |
| 24 | MACHINE CENTER 2 | 2855.12 | 3202.846 | 233.887777 | 262.382457 |
| 25 | AS/RS CART | 2881.51 | 2892.52 | 236.059705 | 236.961669 |
| 26 | AS/RS CART | 3090.55 | 3101.56 | 253.184726 | 254.08669 |
| 27 | AS/RS CART | 3245.77 | 3256.78 | 265.900694 | 266.802658 |
| 28 | AS/RS CART | 3336.7 | 3347.71 | 273.349682 | 274.251645 |
| 29 | AS/RS CART | 3549.3 | 3560.31 | 290.766546 | 291.66351 |
| 30 | MACHINE CENTER 4 | 3670.76 | 3872.528 | 300.716819 | 317.246103 |
| 31 | AS/RS CART | 3806.6 | 3817.61 | 311.845134 | 312.747098 |
| 32 | AS/RS CART | 3849.08 | 3860.09 | 315.32519 | 316.227154 |
| 33 | MACHINE CENTER 5 | 3911.17 | 4440.832 | 320.411741 | 363.80263 |
| 34 | AS/RS CART | 3922.2 | 3933.21 | 321.315343 | 322.217307 |
| 35 | MINI-MOVER-5 | 3928.47 | 4115.898 | 321.828936 | 337.183514 |
| 36 | AS/RS CART | 4414.21 | 4425.22 | 361.621896 | 362.52386 |
| 37 | MACHINE CENTER 1 | 4578.37 | 4957.72 | 375.070248 | 406.147444 |
| 38 | AS/RS CART | 4649.39 | 4660.4 | 380.888365 | 381.790328 |
| 39 | AS/RS CART | 4694.17 | 4705.18 | 384.556842 | 385.458806 |
| 40 | AS/RS CART | 4769.2 | 4780.21 | 390.703466 | 391.60543 |
| 41 | AS/RS CART | 4848.47 | 4859.48 | 397.187441 | 398.089404 |
| 42 | AS/RS CART | 4890.68 | 4901.69 | 400.655378 | 401.557341 |
| 43 | AS/RS CART | 5248.97 | 5259.98 | 430.007291 | 430.909255 |
| 44 | AS/RS CART | 5323.79 | 5334.8 | 436.136712 | 437.038676 |
| 45 | MACHINE CENTER 1 | 5349.26 | 5728.61 | 438.223271 | 469.300468 |
| 46 | AS/RS CART | 5385.14 | 5396.15 | 441.16264 | 442.064604 |
| 47 | MACHINE CENTER 2 | 5413.12 | 5760.946 | 443.454824 | 471.949503 |
| 48 | AS/RS CART | 5602.38 | 5613.39 | 458.958424 | 459.861388 |
| 49 | MINI-MOVER-5 | 5765.51 | 5952.938 | 472.323396 | 487.677815 |
| 50 | AS/RS CART | 5839.33 | 5850.34 | 478.370895 | 479.272852 |
| 51 | MACHINE CENTER 6 | 5850.19 | 6379.852 | 479.26057 | 522.651655 |
| 52 | AS/RS CART | 5954.63 | 5965.64 | 487.816527 | 488.718491 |
| 53 | MACHINE CENTER 3 | 5970.36 | 7160.058 | 489.105164 | 586.567866 |
| 54 | AS/RS CART | 6054.36 | 6065.37 | 495.98663 | 496.888594 |
| 55 | AS/RS CART | 6372.86 | 6383.87 | 522.062474 | 522.964438 |
| 56 | AS/RS CART | 6407.88 | 6418.89 | 524.947775 | 525.849738 |
| 57 | AS/RS CART | 6445.38 | 6456.33 | 528.019858 | 528.921822 |
| 58 | AS/RS CART | 6537.59 | 6548.57 | 535.57[illegible] | [illegible] |
| 59 | AS/RS CART | 6706.2 | 6717.21 | 543.3[illegible] | [illegible] |

| | | | | | |
|---|---|---|---|---|---|
| 60 | AS/RS CART | 6859.03 | 6870.03 | 561.311081 | 562.213045 |
| 61 | AS/RS CART | 6984.24 | 6995.25 | 572.184467 | 573.086431 |
| 62 | AS/RS CART | 7079.82 | 7090.83 | 579.994593 | 580.896557 |
| 63 | AS/RS CART | 7246.68 | 7257.69 | 593.654135 | 594.566099 |
| 64 | MINI-MOVER-5 | 7248.38 | 7435.788 | 593.801785 | 609.159283 |
| 65 | AS/RS CART | 7324.44 | 7335.45 | 600.034407 | 600.936371 |
| 66 | AS/RS CART | 7421.22 | 7432.23 | 607.96284 | 608.864804 |
| 67 | AS/RS CART | 7494.28 | 7495.29 | 613.128855 | 614.030819 |
| 68 | AS/RS CART | 7575 | 7586.01 | 620.56084 | 621.462803 |
| 69 | MINI-MOVER-5 | 7660.2 | 7847.628 | 627.540613 | 642.895131 |
| 70 | MACHINE CENTER 5 | 7696.12 | 8215.782 | 629.664037 | 673.055126 |
| 71 | AS/RS CART | 7744.68 | 7755.69 | 634.461402 | 635.363366 |
| 72 | AS/RS CART | 7847.34 | 7858.35 | 642.871538 | 643.773502 |
| 73 | AS/RS CART | 7891.56 | 7902.57 | 646.494138 | 647.396102 |
| 74 | AS/RS CART | 8048.16 | 8059.17 | 659.323159 | 660.225122 |
| 75 | AS/RS CART | 8340.86 | 8351.87 | 683.285409 | 684.187372 |

DECISION RULE SET= RANDOM/FMFS
TIME SCALING FACTOR= 12.2913 : SIMULATION TIME= 683.410217

| NO. | FAILED COMPONENT | ACTUAL FAILING TIME | ACTUAL RECOVERY TIME | ADJUSTED FAILING TIME | ADJUSTED RECOVERY TIME |
|---|---|---|---|---|---|
| 1 | AS/RS CART | 75.744 | 86.754 | 6.16240756 | 7.05816309 |
| 2 | AS/RS CART | 151.29 | 162.3 | 12.3087062 | 13.2044617 |
| 3 | AS/RS CART | 188.91 | 199.92 | 15.3694076 | 16.2651632 |
| 4 | AS/RS CART | 387.06 | 398.07 | 31.4905685 | 32.386322 |
| 5 | MINI-MOVER-5 | 567.336 | 754.764 | 46.1575261 | 61.4063606 |
| 6 | AS/RS CART | 810.836 | 821.646 | 65.9520146 | 66.8477704 |
| 7 | AS/RS CART | 931.674 | 942.684 | 75.7984679 | 76.6952234 |
| 8 | AS/RS CART | 994.56 | 1005.57 | 80.9157697 | 81.8115252 |
| 9 | MACHINE CENTER 4 | 1038.47 | 1240.238 | 84.4882152 | 100.903729 |
| 10 | AS/RS CART | 1133.85 | 1144.86 | 92.2563114 | 93.1520669 |
| 11 | AS/RS CART | 1255.36 | 1266.37 | 102.13403 | 103.029785 |
| 12 | AS/RS CART | 1292.76 | 1303.77 | 105.176832 | 106.072588 |
| 13 | AS/RS CART | 1344.59 | 1355.6 | 109.393836 | 110.289392 |
| 14 | AS/RS CART | 1386.1 | 1397.11 | 112.770822 | 113.666577 |
| 15 | AS/RS CART | 1551.55 | 1562.56 | 126.231562 | 127.127318 |
| 16 | AS/RS CART | 1720.57 | 1731.58 | 139.982752 | 140.878508 |
| 17 | AS/RS CART | 1822.37 | 1833.38 | 148.265033 | 149.160789 |
| 18 | AS/RS CART | 1914.59 | 1925.6 | 155.767901 | 156.663656 |
| 19 | AS/RS CART | 2005.88 | 2016.89 | 163.203241 | 164.098997 |
| 20 | AS/RS CART | 2111.21 | 2122.22 | 171.764581 | 172.660337 |
| 21 | AS/RS CART | 2283.37 | 2294.38 | 185.771237 | 186.666992 |
| 22 | AS/RS CART | 2561.25 | 2572.26 | 208.378897 | 209.274653 |
| 23 | AS/RS CART | 2689.37 | 2700.38 | 218.80273 | 219.698486 |
| 24 | MACHINE CENTER 2 | 2855.12 | 3202.946 | 232.287878 | 260.586431 |
| 25 | AS/RS CART | 2881.51 | 2892.52 | 234.434825 | 235.330681 |
| 26 | AS/RS CART | 3090.55 | 3101.56 | 251.442077 | 252.337833 |
| 27 | AS/RS CART | 3245.77 | 3256.78 | 264.070521 | 264.966277 |
| 28 | AS/RS CART | 3336.7 | 3347.71 | 271.468437 | 272.364193 |
| 29 | AS/RS CART | 3549.3 | 3560.31 | 288.765224 | 289.66098 |
| 30 | MACHINE CENTER 4 | 3670.76 | 3872.528 | 298.64701 | 315.062524 |
| 31 | AS/RS CART | 3806.6 | 3817.61 | 309.69873 | 310.594486 |
| 32 | AS/RS CART | 3849.08 | 3860.09 | 313.154833 | 314.050589 |
| 33 | MACHINE CENTER 5 | 3911.17 | 4440.832 | 318.206374 | 361.298805 |
| 34 | AS/RS CART | 3922.2 | 3933.21 | 319.103756 | 319.999512 |
| 35 | MINI-MOVER-5 | 3928.47 | 4115.898 | 319.613873 | 334.862709 |
| 36 | AS/RS CART | 4414.21 | 4425.22 | 359.132883 | 360.028639 |
| 37 | MACHINE CENTER 1 | 4578.37 | 4957.72 | 372.488871 | 403.351384 |
| 38 | AS/RS CART | 4649.39 | 4660.4 | 378.266741 | 379.162497 |
| 39 | AS/RS CART | 4694.17 | 4705.18 | 381.909969 | 382.805724 |
| 40 | AS/RS CART | 4769.2 | 4780.21 | 388.014287 | 388.910042 |
| 41 | AS/RS CART | 4848.47 | 4859.48 | 394.463564 | [illegible] |
| 42 | AS/RS CART | 4890.23 | 4901.23 | 397.8977 | [illegible] |

| | | | | | |
|---|---|---|---|---|---|
| 43 | AS/RS CART | 5242.37 | 5253.33 | 427.047536 | 427.943546 |
| 44 | AS/RS CART | 5323.79 | 5334.8 | 433.134819 | 434.030574 |
| 45 | MACHINE CENTER 1 | 5349.26 | 5728.61 | 435.207016 | 466.07031 |
| 46 | AS/RS CART | 5385.14 | 5396.15 | 438.126154 | 439.02191 |
| 47 | MACHINE CENTER 2 | 5413.12 | 5760.946 | 440.402561 | 468.701114 |
| 48 | AS/RS CART | 5602.38 | 5613.39 | 455.800444 | 456.6962 |
| 49 | MINI-MOVER-5 | 5765.51 | 5952.938 | 469.072433 | 484.321263 |
| 50 | AS/RS CART | 5839.33 | 5850.34 | 475.078308 | 475.974063 |
| 51 | MACHINE CENTER 6 | 5850.19 | 6379.852 | 475.961859 | 519.054291 |
| 52 | AS/RS CART | 5954.63 | 5965.64 | 484.458926 | 485.354632 |
| 53 | MACHINE CENTER 3 | 5970.36 | 7160.058 | 485.738693 | 582.53057 |
| 54 | AS/RS CART | 6054.36 | 6065.37 | 492.572795 | 493.468551 |
| 55 | AS/RS CART | 6372.86 | 6383.87 | 518.469181 | 519.364917 |
| 56 | AS/RS CART | 6407.88 | 6418.89 | 521.334603 | 522.230358 |
| 57 | AS/RS CART | 6445.38 | 6456.39 | 524.385541 | 525.281297 |
| 58 | AS/RS CART | 6537.66 | 6548.67 | 531.893291 | 532.789046 |
| 59 | AS/RS CART | 6706.2 | 6717.21 | 545.605428 | 546.501184 |
| 60 | AS/RS CART | 6859.08 | 6870.09 | 558.043494 | 558.93925 |
| 61 | AS/RS CART | 6984.24 | 6995.25 | 568.226306 | 569.122062 |
| 62 | AS/RS CART | 7079.82 | 7090.83 | 576.002539 | 576.898294 |
| 63 | AS/RS CART | 7246.68 | 7257.69 | 589.577934 | 590.47375 |
| 64 | MINI-MOVER-5 | 7248.36 | 7435.788 | 589.714676 | 604.963511 |
| 65 | AS/RS CART | 7324.44 | 7335.45 | 595.90442 | 596.800178 |
| 66 | AS/RS CART | 7421.22 | 7432.23 | 603.778282 | 604.674038 |
| 67 | AS/RS CART | 7464.28 | 7475.29 | 607.28874 | 608.184498 |
| 68 | AS/RS CART | 7575 | 7586.01 | 616.28857 | 617.185326 |
| 69 | MINI-MOVER-5 | 7660.2 | 7847.628 | 623.221303 | 638.470138 |
| 70 | MACHINE CENTER 5 | 7686.12 | 8215.782 | 625.330112 | 668.422543 |
| 71 | AS/RS CART | 7744.68 | 7755.69 | 630.084457 | 630.980213 |
| 72 | AS/RS CART | 7847.34 | 7858.35 | 638.446708 | 639.342462 |
| 73 | AS/RS CART | 7891.56 | 7902.57 | 642.044373 | 642.940129 |
| 74 | AS/RS CART | 8048.16 | 8059.17 | 654.785082 | 655.680848 |
| 75 | AS/RS CART | 8340.66 | 8351.67 | 678.582412 | 679.478168 |

DECISION RULE SET= RANDOM/NINO
TIME SCALING FACTOR= 12.0795 ; SIMULATION TIME= 685.393023

| NO. | FAILED COMPONENT | ACTUAL FAILING TIME | ACTUAL RECOVERY TIME | ADJUSTED FAILING TIME | ADJUSTED RECOVERY TIME |
|---|---|---|---|---|---|
| 1 | AS/RS CART | 75.744 | 86.754 | 6.27045822 | 7.18191873 |
| 2 | AS/RS CART | 151.29 | 162.3 | 12.524525 | 13.4358863 |
| 3 | AS/RS CART | 188.91 | 199.92 | 15.6388823 | 16.5503539 |
| 4 | AS/RS CART | 387.06 | 398.07 | 32.042717 | 32.9541786 |
| 5 | MINI-MOVER-5 | 567.336 | 754.764 | 46.9668447 | 62.4830488 |
| 6 | AS/RS CART | 810.636 | 821.646 | 67.1084069 | 68.0198684 |
| 7 | AS/RS CART | 931.674 | 942.684 | 77.1285235 | 78.0399851 |
| 8 | AS/RS CART | 994.56 | 1005.57 | 82.3345337 | 83.2459953 |
| 9 | MACHINE CENTER 4 | 1038.47 | 1240.233 | 85.968818 | 102.672958 |
| 10 | AS/RS CART | 1133.95 | 1144.96 | 93.8739187 | 94.7853803 |
| 11 | AS/RS CART | 1255.36 | 1266.37 | 103.924831 | 104.836293 |
| 12 | AS/RS CART | 1292.76 | 1303.77 | 107.020986 | 107.932448 |
| 13 | AS/RS CART | 1344.59 | 1355.6 | 111.311727 | 112.223188 |
| 14 | AS/RS CART | 1386.1 | 1397.11 | 114.748127 | 115.659589 |
| 15 | AS/RS CART | 1551.55 | 1562.56 | 128.444886 | 129.356348 |
| 16 | AS/RS CART | 1720.57 | 1731.58 | 142.437187 | 143.348649 |
| 17 | AS/RS CART | 1822.37 | 1833.38 | 150.864888 | 151.77615 |
| 18 | AS/RS CART | 1914.59 | 1925.6 | 158.49911 | 159.410572 |
| 19 | AS/RS CART | 2005.98 | 2016.99 | 166.064821 | 166.976232 |
| 20 | AS/RS CART | 2111.21 | 2122.22 | 174.776274 | 175.687736 |
| 21 | AS/RS CART | 2283.37 | 2294.38 | 189.028516 | 189.939981 |
| 22 | AS/RS CART | 2561.25 | 2572.26 | 212.032783 | 212.944244 |
| 23 | AS/RS CART | 2689.37 | 2700.38 | 222.633182 | 223.550644 |
| 24 | MACHINE CENTER 2 | 2855.12 | 3202.846 | 236.360777 | 265.155512 |
| 25 | AS/RS CART | 2881.51 | 2892.52 | 238.54547 | 239.45[illegible] |

| | | | | | |
|---|---|---|---|---|---|
| 26 | AS/RS CART | 3090.55 | 3101.55 | 255.350322 | 256.782255 |
| 27 | AS/RS CART | 3245.77 | 3256.78 | 253.700891 | 269.812153 |
| 28 | AS/RS CART | 3336.7 | 3347.71 | 278.228321 | 277.139732 |
| 29 | AS/RS CART | 3549.3 | 3560.31 | 293.828387 | 294.739349 |
| 30 | MACHINE CENTER 4 | 3870.76 | 3872.526 | 303.683439 | 320.586779 |
| 31 | AS/RS CART | 3806.8 | 3817.81 | 315.189938 | 316.040399 |
| 32 | AS/RS CART | 3849.08 | 3880.09 | 318.645839 | 319.557101 |
| 33 | MACHINE CENTER 5 | 3911.17 | 4440.832 | 323.785753 | 367.63378 |
| 34 | AS/RS CART | 3922.2 | 3933.21 | 324.69887 | 325.610332 |
| 35 | MINI-MOVER-5 | 3928.47 | 4115.696 | 325.217931 | 340.734136 |
| 36 | AS/RS CART | 4414.21 | 4425.22 | 365.429861 | 366.341322 |
| 37 | MACHINE CENTER 1 | 4578.37 | 4957.72 | 379.019827 | 410.424273 |
| 38 | AS/RS CART | 4649.39 | 4660.4 | 384.89921 | 385.810671 |
| 39 | AS/RS CART | 4694.17 | 4705.18 | 388.606317 | 389.517778 |
| 40 | AS/RS CART | 4769.2 | 4780.21 | 394.817667 | 395.729128 |
| 41 | AS/RS CART | 4848.47 | 4859.48 | 401.380024 | 402.291486 |
| 42 | AS/RS CART | 4890.88 | 4901.89 | 404.874374 | 405.785836 |
| 43 | AS/RS CART | 5248.97 | 5259.98 | 434.53537 | 435.446832 |
| 44 | AS/RS CART | 5323.79 | 5334.8 | 440.728335 | 441.640797 |
| 45 | MACHINE CENTER 1 | 5349.26 | 5766.61 | 442.837866 | 474.242312 |
| 46 | AS/RS CART | 5385.14 | 5396.15 | 445.808188 | 446.719649 |
| 47 | MACHINE CENTER 2 | 5413.12 | 5780.346 | 448.124509 | 478.818244 |
| 48 | AS/RS CART | 5602.38 | 5613.39 | 463.792376 | 464.703837 |
| 49 | MINI-MOVER-5 | 5765.51 | 5952.938 | 477.287074 | 492.813279 |
| 50 | AS/RS CART | 5839.33 | 5850.34 | 483.408254 | 484.319715 |
| 51 | MACHINE CENTER 6 | 5850.19 | 6378.852 | 484.307296 | 528.155305 |
| 52 | AS/RS CART | 5954.63 | 5965.64 | 492.953351 | 493.864813 |
| 53 | MACHINE CENTER 3 | 5970.36 | 7160.058 | 494.255557 | 592.744568 |
| 54 | AS/RS CART | 6054.36 | 6065.37 | 501.209487 | 502.120949 |
| 55 | AS/RS CART | 6372.86 | 6383.87 | 527.559916 | 528.471378 |
| 56 | AS/RS CART | 6407.88 | 6418.89 | 530.475599 | 531.387061 |
| 57 | AS/RS CART | 6445.38 | 6456.39 | 533.580033 | 534.491494 |
| 58 | AS/RS CART | 6537.66 | 6548.67 | 541.219422 | 542.130883 |
| 59 | AS/RS CART | 6706.2 | 6717.21 | 555.171986 | 556.083448 |
| 60 | AS/RS CART | 6859.08 | 6870.09 | 567.828133 | 568.7396 |
| 61 | AS/RS CART | 6984.24 | 6995.25 | 578.189495 | 579.100956 |
| 62 | AS/RS CART | 7079.82 | 7090.83 | 586.102074 | 587.013535 |
| 63 | AS/RS CART | 7246.66 | 7257.69 | 599.81556 | 600.827021 |
| 64 | MINI-MOVER-5 | 7248.36 | 7435.768 | 600.054638 | 615.570843 |
| 65 | AS/RS CART | 7324.44 | 7335.45 | 606.352912 | 607.264374 |
| 66 | AS/RS CART | 7421.22 | 7432.23 | 614.364833 | 615.276295 |
| 67 | AS/RS CART | 7484.28 | 7495.29 | 619.585246 | 620.49671 |
| 68 | AS/RS CART | 7575 | 7586.01 | 627.095483 | 628.006954 |
| 69 | MINI-MOVER-5 | 7660.2 | 7847.628 | 634.148765 | 649.66487 |
| 70 | MACHINE CENTER 5 | 7686.12 | 8215.782 | 636.294549 | 680.142556 |
| 71 | AS/RS CART | 7744.68 | 7755.69 | 641.142431 | 642.053893 |
| 72 | AS/RS CART | 7847.34 | 7858.35 | 649.641128 | 650.55259 |
| 73 | AS/RS CART | 7891.56 | 7902.57 | 653.301875 | 654.213337 |
| 74 | AS/RS CART | 8048.16 | 8059.17 | 666.265988 | 667.177449 |
| 75 | AS/RS CART | 8340.66 | 8351.67 | 690.480567 | 691.392028 |

DECISION RULE SET= RANDOM/WINQ
TIME SCALING FACTOR= 11.8826 : SIMULATION TIME= 706.815355

| NO. | FAILED COMPONENT | ACTUAL FAILING TIME | ACTUAL RECOVERY TIME | ADJUSTED FAILING TIME | ADJUSTED RECOVERY TIME |
|---|---|---|---|---|---|
| 1 | AS/RS CART | 75.744 | 86.754 | 6.37433252 | 7.30032741 |
| 2 | AS/RS CART | 151.29 | 162.3 | 12.732062 | 13.6586235 |
| 3 | AS/RS CART | 188.91 | 199.92 | 15.8980359 | 16.8246027 |
| 4 | AS/RS CART | 387.06 | 398.07 | 32.5736792 | 33.5002441 |
| 5 | MINI-MOVER-5 | 567.336 | 754.784 | 47.7451063 | 63.5194213 |
| 6 | AS/RS CART | 810.636 | 821.646 | 68.2204232 | 69.1469881 |
| 7 | AS/RS CART | 931.674 | 942.684 | 78.4065777 | 79.3331426 |
| 8 | AS/RS CART | 994.56 | 1005.57 | 83.6986538 | 84.6254187 |
| 9 | MACHINE CENTER 4 | 1039.47 | 1240.239 | 87.394173 | 104.374295 |
| 10 | AS/RS CART | 1133.35 | 1144.36 | 95.4234515 | 96.3500164 |

| | | | | | |
|---|---|---|---|---|---|
| 11 | AS/RS CART | 1255.36 | 1266.37 | 104.648312 | 105.573477 |
| 12 | AS/RS CART | 1292.76 | 1303.77 | 108.794372 | 109.720937 |
| 13 | AS/RS CART | 1344.59 | 1355.6 | 113.156212 | 114.082777 |
| 14 | AS/RS CART | 1386.1 | 1397.11 | 116.649555 | 117.57612 |
| 15 | AS/RS CART | 1551.55 | 1562.56 | 130.573275 | 131.49984 |
| 16 | AS/RS CART | 1720.57 | 1731.58 | 144.797435 | 145.724 |
| 17 | AS/RS CART | 1822.37 | 1833.38 | 153.364584 | 154.291148 |
| 18 | AS/RS CART | 1914.59 | 1925.6 | 161.125511 | 162.052076 |
| 19 | AS/RS CART | 2005.96 | 2016.97 | 168.816588 | 169.743154 |
| 20 | AS/RS CART | 2111.21 | 2122.22 | 177.672395 | 178.59896 |
| 21 | AS/RS CART | 2283.37 | 2294.38 | 192.160807 | 193.087372 |
| 22 | AS/RS CART | 2561.25 | 2572.26 | 215.546261 | 216.472826 |
| 23 | AS/RS CART | 2689.37 | 2700.38 | 226.322413 | 227.254978 |
| 24 | MACHINE CENTER 2 | 2855.12 | 3202.946 | 240.27738 | 269.549257 |
| 25 | AS/RS CART | 2881.51 | 2892.52 | 242.498275 | 243.42484 |
| 26 | AS/RS CART | 3090.55 | 3101.56 | 260.090384 | 261.016949 |
| 27 | AS/RS CART | 3245.77 | 3256.78 | 273.153182 | 274.079747 |
| 28 | AS/RS CART | 3336.7 | 3347.71 | 280.805548 | 281.732113 |
| 29 | AS/RS CART | 3549.3 | 3560.31 | 298.697255 | 299.62382 |
| 30 | MACHINE CENTER 4 | 3870.76 | 3872.526 | 308.916823 | 325.899048 |
| 31 | AS/RS CART | 3806.8 | 3817.81 | 320.350785 | 321.27733 |
| 32 | AS/RS CART | 3849.08 | 3860.09 | 323.92574 | 324.852305 |
| 33 | MACHINE CENTER 5 | 3911.17 | 4440.832 | 329.151026 | 373.725618 |
| 34 | AS/RS CART | 3922.2 | 3933.21 | 330.078276 | 331.005841 |
| 35 | MINI-MOVER-5 | 3929.47 | 4115.886 | 330.686938 | 346.380253 |
| 36 | AS/RS CART | 4414.21 | 4425.22 | 371.485197 | 372.411762 |
| 37 | MACHINE CENTER 1 | 4579.37 | 4957.72 | 385.300355 | 417.225197 |
| 38 | AS/RS CART | 4649.39 | 4660.4 | 391.277182 | 392.203727 |
| 39 | AS/RS CART | 4694.17 | 4705.18 | 395.045697 | 395.972262 |
| 40 | AS/RS CART | 4769.2 | 4780.21 | 401.359972 | 402.286537 |
| 41 | AS/RS CART | 4848.47 | 4859.48 | 408.031071 | 408.957636 |
| 42 | AS/RS CART | 4890.65 | 4901.66 | 411.563324 | 412.509888 |
| 43 | AS/RS CART | 5248.97 | 5259.98 | 441.735815 | 442.66238 |
| 44 | AS/RS CART | 5323.79 | 5334.8 | 448.032417 | 448.958982 |
| 45 | MACHINE CENTER 1 | 5349.28 | 5728.61 | 450.175888 | 482.100716 |
| 46 | AS/RS CART | 5385.14 | 5396.15 | 453.185429 | 454.121994 |
| 47 | MACHINE CENTER 2 | 5413.12 | 5760.946 | 455.550132 | 484.822003 |
| 48 | AS/RS CART | 5602.38 | 5613.39 | 471.477623 | 472.404188 |
| 49 | MINI-MOVER-5 | 5765.51 | 5952.938 | 485.2061 | 500.978415 |
| 50 | AS/RS CART | 5839.33 | 5850.34 | 491.418545 | 492.34511 |
| 51 | MACHINE CENTER 6 | 5850.19 | 6379.852 | 492.332486 | 536.907074 |
| 52 | AS/RS CART | 5954.63 | 5965.64 | 501.121809 | 502.048373 |
| 53 | MACHINE CENTER 3 | 5970.36 | 7160.058 | 502.445593 | 602.56861 |
| 54 | AS/RS CART | 6054.36 | 6065.37 | 509.514753 | 510.441318 |
| 55 | AS/RS CART | 6372.66 | 6383.67 | 536.33182 | 537.258385 |
| 56 | AS/RS CART | 6407.88 | 6418.89 | 539.265817 | 540.192383 |
| 57 | AS/RS CART | 6445.38 | 6456.39 | 542.421695 | 543.348258 |
| 58 | AS/RS CART | 6537.66 | 6548.67 | 550.18767 | 551.114235 |
| 59 | AS/RS CART | 6706.2 | 6717.21 | 564.371434 | 565.297999 |
| 60 | AS/RS CART | 6859.08 | 6870.09 | 577.237305 | 578.16387 |
| 61 | AS/RS CART | 6984.24 | 6995.25 | 587.770354 | 588.696919 |
| 62 | AS/RS CART | 7079.82 | 7090.83 | 595.814048 | 596.740613 |
| 63 | AS/RS CART | 7246.68 | 7257.69 | 609.856429 | 610.782993 |
| 64 | MINI-MOVER-5 | 7248.36 | 7435.788 | 609.997812 | 625.771128 |
| 65 | AS/RS CART | 7324.44 | 7335.45 | 616.400451 | 617.327016 |
| 66 | AS/RS CART | 7421.22 | 7432.23 | 624.545133 | 625.471698 |
| 67 | AS/RS CART | 7484.28 | 7495.29 | 629.852053 | 630.778618 |
| 68 | AS/RS CART | 7575 | 7586.01 | 637.486745 | 638.41331 |
| 69 | MINI-MOVER-5 | 7660.2 | 7847.628 | 644.656894 | 660.430209 |
| 70 | MACHINE CENTER 5 | 7686.12 | 8215.762 | 646.838234 | 691.412822 |
| 71 | AS/RS CART | 7744.68 | 7755.69 | 651.766448 | 652.693013 |
| 72 | AS/RS CART | 7847.34 | 7858.35 | 660.405972 | 661.332537 |
| 73 | AS/RS CART | 7891.56 | 7902.57 | 664.12738 | 665.053945 |
| 74 | AS/RS CART | 8048.16 | 8059.17 | 677.306313 | 678.232878 |
| 75 | AS/RS CART | 8340.66 | 8351.67 | 701.922136 | 702.848703 |

DECISION RULE SET= FSFS/RANDOM
TIME SCALING FACTOR= 12.0795 ; SIMULATION TIME= 695.393022

| NO. | FAILED COMPONENT | ACTUAL FAILING TIME | ACTUAL RECOVERY TIME | ADJUSTED FAILING TIME | ADJUSTED RECOVERY TIME |
|---|---|---|---|---|---|
| 1 | AS/RS CART | 75.744 | 86.754 | 6.27045822 | 7.18131978 |
| 2 | AS/RS CART | 151.29 | 162.3 | 12.524525 | 13.4359866 |
| 3 | AS/RS CART | 188.91 | 199.92 | 15.6388923 | 16.5503539 |
| 4 | AS/RS CART | 387.06 | 398.07 | 32.042717 | 32.9541786 |
| 5 | MINI-MOVER-5 | 587.338 | 754.784 | 48.3888447 | 62.4830438 |
| 6 | AS/RS CART | 810.836 | 821.846 | 67.1084089 | 68.0198684 |
| 7 | AS/RS CART | 931.874 | 942.884 | 77.1285235 | 78.0399851 |
| 8 | AS/RS CART | 994.58 | 1005.57 | 82.3345337 | 83.2459853 |
| 9 | MACHINE CENTER 4 | 1038.47 | 1240.238 | 85.968618 | 102.672958 |
| 10 | AS/RS CART | 1133.85 | 1144.86 | 93.8739187 | 94.7853803 |
| 11 | AS/RS CART | 1255.36 | 1266.37 | 103.924631 | 104.836293 |
| 12 | AS/RS CART | 1292.76 | 1303.77 | 107.020886 | 107.932448 |
| 13 | AS/RS CART | 1344.59 | 1355.6 | 111.311727 | 112.223188 |
| 14 | AS/RS CART | 1386.1 | 1397.11 | 114.748127 | 115.659588 |
| 15 | AS/RS CART | 1551.55 | 1562.56 | 128.444888 | 129.356348 |
| 16 | AS/RS CART | 1720.57 | 1731.58 | 142.437187 | 143.348648 |
| 17 | AS/RS CART | 1822.37 | 1833.38 | 150.864688 | 151.77615 |
| 18 | AS/RS CART | 1914.59 | 1925.6 | 158.49811 | 159.410572 |
| 19 | AS/RS CART | 2005.88 | 2016.89 | 166.064821 | 166.976282 |
| 20 | AS/RS CART | 2111.21 | 2122.22 | 174.778274 | 175.687736 |
| 21 | AS/RS CART | 2283.37 | 2294.38 | 189.028518 | 189.939981 |
| 22 | AS/RS CART | 2561.25 | 2572.25 | 212.032733 | 212.944244 |
| 23 | AS/RS CART | 2689.37 | 2700.33 | 222.639182 | 223.550644 |
| 24 | MACHINE CENTER 2 | 2855.12 | 3202.846 | 236.360777 | 265.155512 |
| 25 | AS/RS CART | 2881.51 | 2892.52 | 238.54547 | 239.456931 |
| 26 | AS/RS CART | 3090.55 | 3101.56 | 255.850322 | 256.762263 |
| 27 | AS/RS CART | 3245.77 | 3256.79 | 268.700691 | 269.612153 |
| 28 | AS/RS CART | 3336.7 | 3347.71 | 276.228321 | 277.139782 |
| 29 | AS/RS CART | 3549.3 | 3560.31 | 293.828387 | 294.738649 |
| 30 | MACHINE CENTER 4 | 3670.76 | 3872.528 | 303.883439 | 320.586779 |
| 31 | AS/RS CART | 3806.6 | 3817.61 | 315.128938 | 316.040398 |
| 32 | AS/RS CART | 3849.08 | 3860.09 | 318.645639 | 319.557101 |
| 33 | MACHINE CENTER 5 | 3911.17 | 4440.832 | 323.785753 | 367.63376 |
| 34 | AS/RS CART | 3922.2 | 3933.21 | 324.69887 | 325.610332 |
| 35 | MINI-MOVER-5 | 3928.47 | 4115.886 | 325.217831 | 340.734136 |
| 36 | AS/RS CART | 4414.21 | 4425.22 | 365.429861 | 366.341322 |
| 37 | MACHINE CENTER 1 | 4578.37 | 4957.72 | 379.018827 | 410.424273 |
| 38 | AS/RS CART | 4649.39 | 4660.4 | 384.89921 | 385.810671 |
| 39 | AS/RS CART | 4694.17 | 4705.18 | 388.606317 | 389.517778 |
| 40 | AS/RS CART | 4769.2 | 4780.21 | 394.817667 | 395.729123 |
| 41 | AS/RS CART | 4848.47 | 4859.48 | 401.380024 | 402.291486 |
| 42 | AS/RS CART | 4890.68 | 4901.69 | 404.874374 | 405.785836 |
| 43 | AS/RS CART | 5248.97 | 5259.98 | 434.53537 | 435.446832 |
| 44 | AS/RS CART | 5323.79 | 5334.8 | 440.728335 | 441.640797 |
| 45 | MACHINE CENTER 1 | 5349.26 | 5728.61 | 442.837866 | 474.242312 |
| 46 | AS/RS CART | 5385.14 | 5396.15 | 445.808188 | 446.718648 |
| 47 | MACHINE CENTER 2 | 5413.12 | 5760.846 | 448.124509 | 476.918244 |
| 48 | AS/RS CART | 5602.38 | 5613.39 | 463.792376 | 464.703837 |
| 49 | MINI-MOVER-5 | 5765.51 | 5952.938 | 477.287074 | 492.813279 |
| 50 | AS/RS CART | 5839.33 | 5850.34 | 483.408254 | 484.319715 |
| 51 | MACHINE CENTER 6 | 5850.13 | 6373.852 | 484.307292 | 528.155325 |
| 52 | AS/RS CART | 5954.83 | 5965.84 | 492.953351 | 493.864813 |
| 53 | MACHINE CENTER 3 | 5970.36 | 7160.058 | 494.255557 | 592.744568 |
| 54 | AS/RS CART | 6054.36 | 6065.37 | 501.208487 | 502.120949 |
| 55 | AS/RS CART | 6372.66 | 6383.67 | 527.559916 | 528.471378 |
| 56 | AS/RS CART | 6407.88 | 6418.89 | 530.475589 | 531.387061 |
| 57 | AS/RS CART | 6445.38 | 6456.39 | 533.580033 | 534.491434 |
| 58 | AS/RS CART | 6537.66 | 6548.67 | 541.219422 | 542.130883 |
| 59 | AS/RS CART | 6706.2 | 6717.21 | 555.171986 | 556.083448 |

| | | | | | |
|---|---|---|---|---|---|
| 60 | AS/RS CART | 6359.08 | 6370.09 | 567.823133 | 568.7396 |
| 61 | AS/RS CART | 6484.24 | 6495.25 | 578.189495 | 579.100956 |
| 62 | AS/RS CART | 7079.82 | 7090.83 | 586.108074 | 587.013535 |
| 63 | AS/RS CART | 7246.68 | 7257.69 | 599.91556 | 600.827021 |
| 64 | MINI-MOVER-5 | 7248.36 | 7435.788 | 600.054838 | 615.570843 |
| 65 | AS/RS CART | 7324.44 | 7335.45 | 606.352912 | 607.264374 |
| 66 | AS/RS CART | 7421.22 | 7432.23 | 614.364833 | 615.278295 |
| 67 | AS/RS CART | 7484.28 | 7495.29 | 619.585248 | 620.49871 |
| 68 | AS/RS CART | 7575 | 7586.01 | 627.055493 | 628.008954 |
| 69 | MINI-MOVER-5 | 7660.2 | 7847.828 | 634.148785 | 649.66497 |
| 70 | MACHINE CENTER 5 | 7688.12 | 8215.782 | 636.294549 | 680.142556 |
| 71 | AS/RS CART | 7744.88 | 7755.89 | 641.142431 | 642.053893 |
| 72 | AS/RS CART | 7847.34 | 7858.35 | 649.841128 | 650.55259 |
| 73 | AS/RS CART | 7891.56 | 7902.57 | 653.301875 | 654.213337 |
| 74 | AS/RS CART | 8048.16 | 8059.17 | 666.265986 | 667.177449 |
| 75 | AS/RS CART | 8340.86 | 8351.87 | 690.480567 | 691.392028 |

DECISION RULE SET= FSFS/FMFS
TIME SCALING FACTOR= 12.1907 ; SIMULATION TIME= 630.74971

| NO. | FAILED COMPONENT | ACTUAL FAILING TIME | ACTUAL RECOVERY TIME | ADJUSTED FAILING TIME | ADJUSTED RECOVERY TIME |
|---|---|---|---|---|---|
| 1 | AS/RS CART | 75.744 | 86.754 | 6.22858882 | 7.13336433 |
| 2 | AS/RS CART | 151.29 | 162.3 | 12.4408857 | 13.3482712 |
| 3 | AS/RS CART | 188.81 | 199.82 | 15.5344876 | 16.4388431 |
| 4 | AS/RS CART | 387.06 | 398.07 | 31.8287599 | 32.7341354 |
| 5 | MINI-MOVER-5 | 587.338 | 754.784 | 48.6532354 | 62.085835 |
| 6 | AS/RS CART | 810.838 | 821.848 | 66.6603074 | 67.5658829 |
| 7 | AS/RS CART | 931.674 | 942.684 | 76.6135173 | 77.5188928 |
| 8 | AS/RS CART | 994.56 | 1005.57 | 81.7847857 | 82.6901412 |
| 9 | MACHINE CENTER 4 | 1038.47 | 1240.238 | 85.3855776 | 101.987386 |
| 10 | AS/RS CART | 1133.85 | 1144.86 | 93.2470993 | 94.1524748 |
| 11 | AS/RS CART | 1255.36 | 1266.37 | 103.2308 | 104.136275 |
| 12 | AS/RS CART | 1292.76 | 1303.77 | 106.30638 | 107.211756 |
| 13 | AS/RS CART | 1344.59 | 1355.6 | 110.568471 | 111.473846 |
| 14 | AS/RS CART | 1386.1 | 1397.11 | 113.881925 | 114.887301 |
| 15 | AS/RS CART | 1551.55 | 1562.56 | 127.587228 | 128.492603 |
| 16 | AS/RS CART | 1720.57 | 1731.58 | 141.486039 | 142.391474 |
| 17 | AS/RS CART | 1822.37 | 1833.38 | 149.857327 | 150.762703 |
| 18 | AS/RS CART | 1914.59 | 1925.6 | 157.440772 | 158.346148 |
| 19 | AS/RS CART | 2005.88 | 2016.89 | 164.955965 | 165.86134 |
| 20 | AS/RS CART | 2111.21 | 2122.22 | 173.60925 | 174.514625 |
| 21 | AS/RS CART | 2283.37 | 2294.38 | 187.766329 | 188.671705 |
| 22 | AS/RS CART | 2561.25 | 2572.26 | 210.616988 | 211.522363 |
| 23 | AS/RS CART | 2689.37 | 2700.38 | 221.152565 | 222.057941 |
| 24 | MACHINE CENTER 2 | 2855.12 | 3202.946 | 234.782537 | 263.365003 |
| 25 | AS/RS CART | 2881.51 | 2892.52 | 236.952643 | 237.858018 |
| 26 | AS/RS CART | 3090.55 | 3101.56 | 254.142443 | 255.047818 |
| 27 | AS/RS CART | 3245.77 | 3256.78 | 266.90651 | 267.811886 |
| 28 | AS/RS CART | 3336.7 | 3347.71 | 274.383876 | 275.289251 |
| 29 | AS/RS CART | 3549.3 | 3560.31 | 291.866422 | 292.771798 |
| 30 | MACHINE CENTER 4 | 3670.76 | 3872.529 | 301.854334 | 318.446142 |
| 31 | AS/RS CART | 3806.6 | 3817.61 | 313.024744 | 313.930119 |
| 32 | AS/RS CART | 3849.08 | 3860.09 | 316.517964 | 317.423333 |
| 33 | MACHINE CENTER 5 | 3911.17 | 4440.832 | 321.623755 | 365.178978 |
| 34 | AS/RS CART | 3922.2 | 3933.21 | 322.530775 | 323.436151 |
| 35 | MINI-MOVER-5 | 3928.47 | 4115.889 | 323.046371 | 338.45897 |
| 36 | AS/RS CART | 4414.21 | 4425.22 | 362.989795 | 363.895171 |
| 37 | MACHINE CENTER 1 | 4578.37 | 4957.72 | 376.489018 | 407.583768 |
| 38 | AS/RS CART | 4649.39 | 4660.4 | 382.329142 | 383.234518 |
| 39 | AS/RS CART | 4694.17 | 4705.18 | 386.011496 | 386.916872 |
| 40 | AS/RS CART | 4769.2 | 4780.21 | 392.181371 | 393.086747 |
| 41 | AS/RS CART | 4848.47 | 4859.48 | 398.69331 | 399.605286 |
| 42 | AS/RS CART | 4920.38 | 4931.39 | 422.172336 | [illegible] |

| | | | | | |
|---|---|---|---|---|---|
| 43 | AS/RS CART | 5243.97 | 5259.98 | 431.63387 | 432.539245 |
| 44 | AS/RS CART | 5323.79 | 5334.8 | 437.786478 | 438.691852 |
| 45 | MACHINE CENTER 1 | 5349.28 | 5728.81 | 439.880928 | 471.075878 |
| 46 | AS/RS CART | 5385.14 | 5398.15 | 442.831418 | 443.736791 |
| 47 | MACHINE CENTER 2 | 5413.12 | 5760.948 | 445.13227 | 473.734736 |
| 48 | AS/RS CART | 5602.38 | 5613.39 | 460.895519 | 461.600895 |
| 49 | MINI-MOVER-5 | 5765.51 | 5952.938 | 474.110843 | 489.522843 |
| 50 | AS/RS CART | 5839.33 | 5850.34 | 480.180417 | 481.085793 |
| 51 | MACHINE CENTER 6 | 5850.19 | 6379.852 | 481.073458 | 524.828881 |
| 52 | AS/RS CART | 5954.83 | 5965.84 | 489.86178 | 490.587155 |
| 53 | MACHINE CENTER 3 | 5970.38 | 7160.058 | 490.95529 | 588.788865 |
| 54 | AS/RS CART | 6054.36 | 6065.37 | 497.862788 | 498.768163 |
| 55 | AS/RS CART | 6372.86 | 6383.87 | 524.037287 | 524.942843 |
| 56 | AS/RS CART | 6407.88 | 6418.89 | 526.933483 | 527.838858 |
| 57 | AS/RS CART | 6445.38 | 6456.39 | 530.017187 | 530.922562 |
| 58 | AS/RS CART | 6537.86 | 6548.97 | 537.605565 | 538.510841 |
| 59 | AS/RS CART | 6706.2 | 6717.21 | 551.484965 | 552.370341 |
| 60 | AS/RS CART | 6859.08 | 6870.09 | 564.03881 | 564.941985 |
| 61 | AS/RS CART | 6984.24 | 6995.25 | 574.32878 | 575.234158 |
| 62 | AS/RS CART | 7079.82 | 7090.83 | 582.188525 | 583.093901 |
| 63 | AS/RS CART | 7246.88 | 7257.89 | 595.908775 | 596.81515 |
| 64 | MINI-MOVER-5 | 7248.39 | 7435.788 | 596.047925 | 611.480525 |
| 65 | AS/RS CART | 7324.44 | 7335.45 | 602.304144 | 603.209519 |
| 66 | AS/RS CART | 7421.22 | 7432.23 | 610.282597 | 611.187943 |
| 67 | AS/RS CART | 7484.28 | 7495.29 | 615.448124 | 616.353489 |
| 68 | AS/RS CART | 7575 | 7586.01 | 622.908221 | 623.813597 |
| 69 | MINI-MOVER-5 | 7660.2 | 7847.628 | 629.914397 | 645.326996 |
| 70 | MACHINE CENTER 5 | 7686.12 | 8215.782 | 632.045853 | 675.801076 |
| 71 | AS/RS CART | 7744.88 | 7755.89 | 636.861365 | 637.78674 |
| 72 | AS/RS CART | 7847.34 | 7858.35 | 645.303313 | 646.208889 |
| 73 | AS/RS CART | 7891.56 | 7902.57 | 648.939617 | 649.844993 |
| 74 | AS/RS CART | 8048.16 | 8059.17 | 661.817165 | 662.722541 |
| 75 | AS/RS CART | 8340.66 | 8351.67 | 685.870057 | 686.775432 |

DECISION RULE SET= F3F3/MINQ
TIME SCALING FACTOR= 11.9819 ; SIMULATION TIME= 701.083278

| NO. | FAILED COMPONENT | ACTUAL FAILING TIME | ACTUAL RECOVERY TIME | ADJUSTED FAILING TIME | ADJUSTED RECOVERY TIME |
|---|---|---|---|---|---|
| 1 | AS/RS CART | 75.744 | 86.754 | 6.32158775 | 7.2404814 |
| 2 | AS/RS CART | 151.29 | 162.3 | 12.6266504 | 13.5455441 |
| 3 | AS/RS CART | 188.91 | 199.92 | 15.7664124 | 16.6853061 |
| 4 | AS/RS CART | 387.06 | 398.07 | 32.3038844 | 33.222383 |
| 5 | MINI-MOVER-5 | 567.336 | 754.764 | 47.3488139 | 62.9925387 |
| 6 | AS/RS CART | 810.636 | 821.646 | 67.6556111 | 68.5745048 |
| 7 | AS/RS CART | 931.674 | 942.684 | 77.7574321 | 78.6763258 |
| 8 | AS/RS CART | 994.56 | 1005.57 | 83.0058923 | 83.924786 |
| 9 | MACHINE CENTER 4 | 1038.47 | 1240.238 | 86.6706172 | 103.510157 |
| 10 | AS/RS CART | 1133.85 | 1144.56 | 94.6393698 | 95.5582634 |
| 11 | AS/RS CART | 1255.36 | 1266.37 | 104.772238 | 105.691132 |
| 12 | AS/RS CART | 1292.76 | 1303.77 | 107.893638 | 108.812532 |
| 13 | AS/RS CART | 1344.59 | 1355.6 | 112.219366 | 113.13826 |
| 14 | AS/RS CART | 1386.1 | 1397.11 | 115.683787 | 116.602681 |
| 15 | AS/RS CART | 1551.55 | 1562.56 | 129.49223 | 130.411124 |
| 16 | AS/RS CART | 1720.57 | 1731.58 | 143.598625 | 144.517518 |
| 17 | AS/RS CART | 1822.37 | 1833.38 | 152.094844 | 153.013738 |
| 18 | AS/RS CART | 1914.59 | 1925.6 | 159.791517 | 160.710411 |
| 19 | AS/RS CART | 2005.88 | 2016.89 | 167.418819 | 168.337812 |
| 20 | AS/RS CART | 2111.21 | 2122.22 | 176.201406 | 177.120299 |
| 21 | AS/RS CART | 2283.37 | 2294.38 | 190.569864 | 191.488758 |
| 22 | AS/RS CART | 2561.25 | 2572.26 | 213.761705 | 214.680599 |
| 23 | AS/RS CART | 2689.37 | 2700.38 | 224.454589 | 225.373483 |
| 24 | MACHINE CENTER 2 | 2855.12 | 3202.946 | 238.28807 | 267.317598 |
| 25 | AS/RS CART | 2881.51 | 2892.52 | 240.490578 | 241.409471 |
| 26 | AS/RS CART | 3090.55 | 3101.56 | 257.937038 | 258.855932 |
| 27 | AS/RS CART | 3245.77 | 3256.78 | 270.891686 | 271.810579 |

| | | | | | |
|---|---|---|---|---|---|
| 28 | AS/RS CART | 3336.7 | 3347.71 | 278.480698 | 279.399589 |
| 29 | AS/RS CART | 3549.3 | 3560.31 | 296.224274 | 297.143187 |
| 30 | MACHINE CENTER 4 | 3670.78 | 3872.528 | 306.381315 | 323.200855 |
| 31 | AS/RS CART | 3806.6 | 3817.61 | 317.69851 | 318.617403 |
| 32 | AS/RS CART | 3849.88 | 3860.89 | 321.243897 | 322.16278 |
| 33 | MACHINE CENTER 5 | 3911.17 | 4440.032 | 326.425813 | 370.831458 |
| 34 | AS/RS CART | 3922.2 | 3933.21 | 327.349478 | 328.268369 |
| 35 | MINI-MOVER-5 | 3926.47 | 4115.896 | 327.699769 | 343.512494 |
| 36 | AS/RS CART | 4414.21 | 4425.22 | 368.408586 | 369.328482 |
| 37 | MACHINE CENTER 1 | 4578.37 | 4957.72 | 382.118368 | 413.778086 |
| 38 | AS/RS CART | 4649.38 | 4660.4 | 388.03799 | 388.958584 |
| 39 | AS/RS CART | 4694.17 | 4705.18 | 391.775828 | 392.693819 |
| 40 | AS/RS CART | 4769.2 | 4780.21 | 398.037623 | 398.955817 |
| 41 | AS/RS CART | 4848.47 | 4859.48 | 404.65266 | 405.571704 |
| 42 | AS/RS CART | 4890.88 | 4901.89 | 408.175733 | 409.094627 |
| 43 | AS/RS CART | 5248.97 | 5259.98 | 438.078586 | 438.99748 |
| 44 | AS/RS CART | 5323.79 | 5334.8 | 444.323857 | 445.24185 |
| 45 | MACHINE CENTER 1 | 5349.88 | 5728.61 | 446.498781 | 478.109289 |
| 46 | AS/RS CART | 5385.14 | 5396.15 | 449.443323 | 450.362216 |
| 47 | MACHINE CENTER 2 | 5413.12 | 5760.646 | 451.778531 | 480.880659 |
| 48 | AS/RS CART | 5602.38 | 5613.38 | 467.574155 | 468.493048 |
| 49 | MINI-MOVER-5 | 5765.51 | 5852.838 | 481.18897 | 488.831695 |
| 50 | AS/RS CART | 5839.33 | 5850.34 | 487.348881 | 488.268875 |
| 51 | MACHINE CENTER 6 | 5850.18 | 6378.652 | 488.258355 | 532.481601 |
| 52 | AS/RS CART | 5854.63 | 5865.64 | 488.872908 | 487.891803 |
| 53 | MACHINE CENTER 3 | 5870.38 | 7160.856 | 489.925734 | 597.577627 |
| 54 | AS/RS CART | 6054.36 | 6065.37 | 505.288399 | 506.21526 |
| 55 | AS/RS CART | 6372.69 | 6383.67 | 531.861957 | 532.780551 |
| 56 | AS/RS CART | 6407.88 | 6418.89 | 534.801115 | 535.720008 |
| 57 | AS/RS CART | 6445.36 | 6456.38 | 537.930892 | 538.849756 |
| 58 | AS/RS CART | 6537.68 | 6548.67 | 545.632543 | 546.551437 |
| 59 | AS/RS CART | 6706.2 | 6717.21 | 559.698977 | 560.61777 |
| 60 | AS/RS CART | 6859.69 | 6870.68 | 572.458228 | 573.377122 |
| 61 | AS/RS CART | 6984.24 | 6995.25 | 582.904072 | 583.822965 |
| 62 | AS/RS CART | 7079.62 | 7090.63 | 590.88117 | 591.800064 |
| 63 | AS/RS CART | 7246.69 | 7257.69 | 604.807291 | 605.726185 |
| 64 | MINI-MOVER-5 | 7248.36 | 7435.768 | 604.947564 | 620.590228 |
| 65 | AS/RS CART | 7324.44 | 7335.45 | 611.297134 | 612.216028 |
| 66 | AS/RS CART | 7421.22 | 7432.23 | 619.374385 | 620.293279 |
| 67 | AS/RS CART | 7484.26 | 7495.26 | 624.637367 | 625.556261 |
| 68 | AS/RS CART | 7575 | 7586.01 | 632.20885 | 633.127744 |
| 69 | MINI-MOVER-5 | 7660.2 | 7847.628 | 639.318635 | 654.96236 |
| 70 | MACHINE CENTER 5 | 7686.12 | 8215.782 | 641.482618 | 685.668461 |
| 71 | AS/RS CART | 7744.68 | 7755.69 | 646.370329 | 647.289222 |
| 72 | AS/RS CART | 7847.34 | 7858.35 | 654.938323 | 655.857217 |
| 73 | AS/RS CART | 7891.56 | 7902.57 | 658.628921 | 659.547815 |
| 74 | AS/RS CART | 8048.16 | 8059.17 | 671.698744 | 672.617637 |
| 75 | AS/RS CART | 8340.66 | 8351.67 | 696.110768 | 697.029662 |

DECISION RULE SET= FSFS/WINQ
TIME SCALING FACTOR= 11.8065 : SIMULATION TIME= 711.472484

| NO. | FAILED COMPONENT | ACTUAL FAILING TIME | ACTUAL RECOVERY TIME | ADJUSTED FAILING TIME | ADJUSTED RECOVERY TIME |
|---|---|---|---|---|---|
| 1 | AS/RS CART | 75.744 | 86.754 | 6.41544812 | 7.34798628 |
| 2 | AS/RS CART | 151.28 | 162.3 | 12.8141276 | 13.746665 |
| 3 | AS/RS CART | 188.91 | 198.92 | 16.0005082 | 16.8330454 |
| 4 | AS/RS CART | 387.06 | 398.07 | 32.7836361 | 33.7161733 |
| 5 | MINI-MOVER-5 | 567.338 | 754.764 | 48.0528523 | 63.9278364 |
| 6 | AS/RS CART | 810.636 | 821.646 | 68.6601449 | 69.592682 |
| 7 | AS/RS CART | 931.674 | 942.684 | 78.9119553 | 79.8444924 |
| 8 | AS/RS CART | 994.56 | 1005.57 | 84.2383433 | 85.1708804 |
| 9 | MACHINE CENTER 4 | 1038.47 | 1240.238 | 87.9574811 | 105.04705 |
| 10 | AS/RS CART | 1133.95 | 1144.36 | 96.0445517 | 96.9770889 |

| | | | | | |
|---|---|---|---|---|---|
| 11 | AS/RS CART | 1255.36 | 1266.37 | 106.32737 | 107.260427 |
| 12 | AS/RS CART | 1292.76 | 1303.77 | 109.495617 | 110.428154 |
| 13 | AS/RS CART | 1344.59 | 1355.6 | 113.885572 | 114.818109 |
| 14 | AS/RS CART | 1386.1 | 1397.11 | 117.401431 | 118.333969 |
| 15 | AS/RS CART | 1551.55 | 1562.56 | 131.414899 | 132.347436 |
| 16 | AS/RS CART | 1720.57 | 1731.58 | 145.730742 | 146.663279 |
| 17 | AS/RS CART | 1822.37 | 1833.38 | 154.353111 | 155.285648 |
| 18 | AS/RS CART | 1914.59 | 1925.6 | 162.164062 | 163.096599 |
| 19 | AS/RS CART | 2005.98 | 2016.99 | 169.904714 | 170.837251 |
| 20 | AS/RS CART | 2111.21 | 2122.22 | 178.9178 | 179.750133 |
| 21 | AS/RS CART | 2283.37 | 2294.38 | 183.398399 | 184.331936 |
| 22 | AS/RS CART | 2561.25 | 2572.26 | 216.935586 | 217.868124 |
| 23 | AS/RS CART | 2689.37 | 2700.38 | 227.787236 | 228.719773 |
| 24 | MACHINE CENTER 2 | 2855.12 | 3202.348 | 241.826113 | 271.288664 |
| 25 | AS/RS CART | 2881.51 | 2892.52 | 244.061322 | 244.993853 |
| 26 | AS/RS CART | 3090.55 | 3101.56 | 261.766823 | 262.699361 |
| 27 | AS/RS CART | 3245.77 | 3256.78 | 274.913819 | 275.846356 |
| 28 | AS/RS CART | 3336.7 | 3347.71 | 282.615509 | 283.548046 |
| 29 | AS/RS CART | 3549.3 | 3560.31 | 300.622539 | 301.555076 |
| 30 | MACHINE CENTER 4 | 3670.78 | 3872.528 | 310.910032 | 327.888661 |
| 31 | AS/RS CART | 3806.6 | 3817.61 | 322.415619 | 323.348156 |
| 32 | AS/RS CART | 3849.08 | 3860.09 | 326.013637 | 326.946174 |
| 33 | MACHINE CENTER 5 | 3911.17 | 4440.332 | 331.272604 | 376.134502 |
| 34 | AS/RS CART | 3922.2 | 3933.21 | 332.206835 | 333.139373 |
| 35 | MINI-MOVER-5 | 3926.47 | 4115.896 | 332.737898 | 348.612883 |
| 36 | AS/RS CART | 4414.21 | 4425.22 | 373.879643 | 374.81218 |
| 37 | MACHINE CENTER 1 | 4578.37 | 4857.72 | 387.783849 | 418.914454 |
| 38 | AS/RS CART | 4649.39 | 4660.4 | 393.799179 | 394.731716 |
| 39 | AS/RS CART | 4694.17 | 4705.18 | 397.592004 | 398.524542 |
| 40 | AS/RS CART | 4769.2 | 4780.21 | 403.946978 | 404.879516 |
| 41 | AS/RS CART | 4848.47 | 4859.48 | 410.661077 | 411.593614 |
| 42 | AS/RS CART | 4890.68 | 4901.69 | 414.236226 | 415.168763 |
| 43 | AS/RS CART | 5248.97 | 5259.98 | 444.583069 | 445.515606 |
| 44 | AS/RS CART | 5323.79 | 5334.8 | 450.920256 | 451.852793 |
| 45 | MACHINE CENTER 1 | 5349.26 | 5728.61 | 453.077542 | 485.208148 |
| 46 | AS/RS CART | 5385.14 | 5396.15 | 456.116546 | 457.049083 |
| 47 | MACHINE CENTER 2 | 5413.12 | 5760.846 | 458.486427 | 487.946879 |
| 48 | AS/RS CART | 5602.38 | 5613.39 | 474.51658 | 475.449117 |
| 49 | MINI-MOVER-5 | 5765.51 | 5952.938 | 488.333545 | 504.20853 |
| 50 | AS/RS CART | 5839.33 | 5850.34 | 494.588033 | 495.51257 |
| 51 | MACHINE CENTER 6 | 5850.19 | 6379.852 | 495.505865 | 540.367783 |
| 52 | AS/RS CART | 5954.63 | 5965.64 | 504.35184 | 505.284378 |
| 53 | MACHINE CENTER 3 | 5970.36 | 7160.058 | 505.884157 | 606.450515 |
| 54 | AS/RS CART | 6054.36 | 6065.37 | 512.798882 | 513.73142 |
| 55 | AS/RS CART | 6372.66 | 6383.67 | 539.958608 | 540.891145 |
| 56 | AS/RS CART | 6407.88 | 6418.89 | 542.741711 | 543.674248 |
| 57 | AS/RS CART | 6445.38 | 6456.39 | 545.917927 | 546.850464 |
| 58 | AS/RS CART | 6537.86 | 6548.87 | 553.73396 | 554.666497 |
| 59 | AS/RS CART | 6706.2 | 6717.21 | 568.008148 | 568.940685 |
| 60 | AS/RS CART | 6859.08 | 6870.09 | 580.357947 | 581.290484 |
| 61 | AS/RS CART | 6984.24 | 6995.25 | 591.558887 | 592.491424 |
| 62 | AS/RS CART | 7079.82 | 7090.83 | 599.654428 | 600.586965 |
| 63 | AS/RS CART | 7246.68 | 7257.69 | 613.78732 | 614.719853 |
| 64 | MINI-MOVER-5 | 7248.36 | 7435.788 | 613.829815 | 629.104593 |
| 65 | AS/RS CART | 7324.44 | 7335.45 | 620.373523 | 621.30606 |
| 66 | AS/RS CART | 7421.22 | 7432.23 | 628.570703 | 629.50324 |
| 67 | AS/RS CART | 7484.28 | 7495.29 | 633.911328 | 634.844365 |
| 68 | AS/RS CART | 7575 | 7586.01 | 641.595731 | 642.528268 |
| 69 | MINI-MOVER-5 | 7680.2 | 7947.628 | 643.812035 | 654.887075 |
| 70 | MACHINE CENTER 5 | 7686.12 | 8215.732 | 651.007486 | 695.863394 |
| 71 | AS/RS CART | 7744.68 | 7755.69 | 655.367476 | 656.300013 |
| 72 | AS/RS CART | 7847.34 | 7858.35 | 664.662686 | 665.595223 |
| 73 | AS/RS CART | 7891.56 | 7902.57 | 668.408081 | 669.340618 |
| 74 | AS/RS CART | 8048.16 | 8059.17 | 681.671961 | 682.604498 |
| 75 | AS/RS CART | 8340.66 | 8351.67 | 706.446443 | 707.378980 |

DECISION RULE SET= SPT/RANDOM
TIME SCALING FACTOR= 11.8966 ; SIMULATION TIME= 709.084092

| NO. | FAILED COMPONENT | ACTUAL FAILING TIME | ACTUAL RECOVERY TIME | ADJUSTED FAILING TIME | ADJUSTED RECOVERY TIME |
|---|---|---|---|---|---|
| 1 | AS/RS CART | 75.744 | 86.754 | 6.36686112 | 7.29233563 |
| 2 | AS/RS CART | 151.29 | 162.3 | 12.7170786 | 13.6425533 |
| 3 | AS/RS CART | 188.91 | 199.92 | 15.8793268 | 16.8048014 |
| 4 | AS/RS CART | 387.06 | 398.07 | 32.5353483 | 33.4609207 |
| 5 | MINI-MOVER-5 | 567.336 | 754.764 | 47.6889135 | 63.443873 |
| 6 | AS/RS CART | 810.636 | 821.646 | 68.1401409 | 69.0656154 |
| 7 | AS/RS CART | 931.674 | 942.684 | 78.3143083 | 79.2397828 |
| 8 | AS/RS CART | 994.56 | 1005.57 | 83.6003564 | 84.5258309 |
| 9 | MACHINE CENTER 4 | 1038.47 | 1240.838 | 87.2913265 | 104.251467 |
| 10 | AS/RS CART | 1133.95 | 1144.96 | 95.3171485 | 96.2426239 |
| 11 | AS/RS CART | 1255.36 | 1266.37 | 105.522586 | 106.448061 |
| 12 | AS/RS CART | 1292.76 | 1303.77 | 108.666342 | 109.591816 |
| 13 | AS/RS CART | 1344.59 | 1355.6 | 113.023049 | 113.948523 |
| 14 | AS/RS CART | 1386.1 | 1397.11 | 116.512281 | 117.437755 |
| 15 | AS/RS CART | 1551.55 | 1562.56 | 130.418616 | 131.34509 |
| 16 | AS/RS CART | 1720.57 | 1731.58 | 144.627036 | 145.552511 |
| 17 | AS/RS CART | 1822.37 | 1833.38 | 153.184103 | 154.108579 |
| 18 | AS/RS CART | 1914.59 | 1925.6 | 160.935888 | 161.861372 |
| 19 | AS/RS CART | 2005.88 | 2016.89 | 168.617925 | 169.543393 |
| 20 | AS/RS CART | 2111.21 | 2122.22 | 177.463308 | 178.388783 |
| 21 | AS/RS CART | 2283.37 | 2294.38 | 191.93467 | 192.860145 |
| 22 | AS/RS CART | 2561.25 | 2572.26 | 215.292805 | 216.218279 |
| 23 | AS/RS CART | 2689.37 | 2700.38 | 226.062068 | 226.987543 |
| 24 | MACHINE CENTER 8 | 2855.12 | 3202.946 | 239.99462 | 269.232049 |
| 25 | AS/RS CART | 2881.51 | 2892.52 | 242.212601 | 243.138376 |
| 26 | AS/RS CART | 3090.55 | 3101.56 | 259.784308 | 260.709783 |
| 27 | AS/RS CART | 3245.77 | 3256.78 | 272.831733 | 273.757208 |
| 28 | AS/RS CART | 3336.7 | 3347.71 | 280.475094 | 281.400568 |
| 29 | AS/RS CART | 3549.3 | 3560.31 | 298.345746 | 299.27122 |
| 30 | MACHINE CENTER 4 | 3670.76 | 3872.526 | 308.555386 | 325.515525 |
| 31 | AS/RS CART | 3806.6 | 3817.61 | 319.973774 | 320.899249 |
| 32 | AS/RS CART | 3849.08 | 3860.09 | 323.544542 | 324.470017 |
| 33 | MACHINE CENTER 5 | 3911.17 | 4440.832 | 328.76388 | 373.285813 |
| 34 | AS/RS CART | 3922.2 | 3933.21 | 329.690836 | 330.616311 |
| 35 | MINI-MOVER-5 | 3928.47 | 4115.898 | 330.217877 | 345.972831 |
| 36 | AS/RS CART | 4414.21 | 4425.22 | 371.048031 | 371.973505 |
| 37 | MACHINE CENTER 1 | 4578.37 | 4957.72 | 384.846831 | 416.734133 |
| 38 | AS/RS CART | 4649.39 | 4660.4 | 390.816704 | 391.742179 |
| 39 | AS/RS CART | 4694.17 | 4705.18 | 394.580805 | 395.506279 |
| 40 | AS/RS CART | 4769.2 | 4780.21 | 400.887649 | 401.813123 |
| 41 | AS/RS CART | 4848.47 | 4859.48 | 407.550897 | 408.476371 |
| 42 | AS/RS CART | 4890.68 | 4901.69 | 411.09897 | 412.024444 |
| 43 | AS/RS CART | 5248.97 | 5259.98 | 441.215978 | 442.141452 |
| 44 | AS/RS CART | 5323.79 | 5334.8 | 447.50517 | 448.430644 |
| 45 | MACHINE CENTER 1 | 5349.26 | 5728.61 | 449.646117 | 481.53338 |
| 46 | AS/RS CART | 5385.14 | 5396.15 | 452.662105 | 453.58758 |
| 47 | MACHINE CENTER 2 | 5413.12 | 5760.946 | 455.014038 | 484.251437 |
| 48 | AS/RS CART | 5602.38 | 5613.39 | 470.922785 | 471.848259 |
| 49 | MINI-MOVER-5 | 5765.51 | 5952.938 | 484.635106 | 500.389853 |
| 50 | AS/RS CART | 5839.33 | 5850.34 | 490.84024 | 491.765715 |
| 51 | MACHINE CENTER 6 | 5850.19 | 6379.852 | 491.753106 | 536.275232 |
| 52 | AS/RS CART | 5954.63 | 5965.64 | 500.532085 | 501.457559 |
| 53 | MACHINE CENTER 3 | 5970.38 | 7160.058 | 501.854311 | 601.857506 |
| 54 | AS/RS CART | 6054.36 | 6065.37 | 508.915153 | 509.840627 |
| 55 | AS/RS CART | 6372.66 | 6383.67 | 535.670636 | 536.59617 |
| 56 | AS/RS CART | 6407.98 | 6418.39 | 538.631206 | 539.55663 |
| 57 | AS/RS CART | 6445.36 | 6456.39 | 541.793367 | 542.708641 |
| 58 | AS/RS CART | 6537.66 | 6548.67 | 549.540205 | 550.465679 |
| 59 | AS/RS CART | 6702.2 | 6717.21 | [illegible] | [illegible] |

| | | | | | |
|---|---|---|---|---|---|
| 60 | AS/RS CART | 6359.03 | 6370.03 | 576.559028 | 577.483483 |
| 61 | AS/RS CART | 6984.24 | 6995.25 | 587.075661 | 588.004136 |
| 62 | AS/RS CART | 7079.82 | 7090.83 | 595.11289 | 596.038384 |
| 63 | AS/RS CART | 7246.68 | 7257.69 | 609.138745 | 610.06422 |
| 64 | MINI-MOVER-5 | 7248.38 | 7435.788 | 609.279883 | 625.034716 |
| 65 | AS/RS CART | 7324.44 | 7335.45 | 615.675087 | 616.600541 |
| 66 | AS/RS CART | 7421.22 | 7432.23 | 623.810164 | 624.735633 |
| 67 | AS/RS CART | 7484.28 | 7495.29 | 629.110838 | 630.036313 |
| 68 | AS/RS CART | 7575 | 7586.01 | 636.738547 | 637.662021 |
| 69 | MINI-MOVER-5 | 7680.2 | 7847.628 | 643.898257 | 658.65301 |
| 70 | MACHINE CENTER 5 | 7688.12 | 8215.782 | 646.07703 | 690.599163 |
| 71 | AS/RS CART | 7744.68 | 7755.69 | 650.999445 | 651.92492 |
| 72 | AS/RS CART | 7847.34 | 7858.35 | 659.628802 | 660.554278 |
| 73 | AS/RS CART | 7891.56 | 7902.57 | 663.34593 | 664.271305 |
| 74 | AS/RS CART | 8048.16 | 8059.17 | 676.509255 | 677.434729 |
| 75 | AS/RS CART | 8340.86 | 8351.87 | 701.088112 | 702.021536 |

DECISION RULE SET= SPT/FMFS
TIME SCALING FACTOR= 12.1248 ; SIMULATION TIME= 832.794933

| NO. | FAILED COMPONENT | ACTUAL FAILING TIME | ACTUAL RECOVERY TIME | ADJUSTED FAILING TIME | ADJUSTED RECOVERY TIME |
|---|---|---|---|---|---|
| 1 | AS/RS CART | 75.744 | 86.754 | 6.24703088 | 7.1550871 |
| 2 | AS/RS CART | 151.29 | 162.3 | 12.4777316 | 13.3857878 |
| 3 | AS/RS CART | 188.91 | 199.92 | 15.5804632 | 16.4885134 |
| 4 | AS/RS CART | 387.06 | 398.07 | 31.9230008 | 32.831057 |
| 5 | MINI-MOVER-5 | 567.336 | 754.764 | 46.7913698 | 62.2488041 |
| 6 | AS/RS CART | 810.636 | 821.646 | 66.8576802 | 67.7657363 |
| 7 | AS/RS CART | 931.674 | 942.684 | 76.8403603 | 77.7484165 |
| 8 | AS/RS CART | 994.56 | 1005.57 | 82.02692 | 82.9349762 |
| 9 | MACHINE CENTER 4 | 1038.47 | 1240.238 | 85.6484231 | 102.289357 |
| 10 | AS/RS CART | 1133.95 | 1144.96 | 93.5231822 | 94.4312483 |
| 11 | AS/RS CART | 1255.36 | 1266.37 | 103.536553 | 104.444608 |
| 12 | AS/RS CART | 1292.76 | 1303.77 | 106.62114 | 107.529196 |
| 13 | AS/RS CART | 1344.59 | 1355.6 | 110.89585 | 111.803926 |
| 14 | AS/RS CART | 1386.1 | 1397.11 | 114.319411 | 115.227466 |
| 15 | AS/RS CART | 1551.55 | 1562.56 | 127.964997 | 128.873054 |
| 16 | AS/RS CART | 1720.57 | 1731.58 | 141.905021 | 142.813077 |
| 17 | AS/RS CART | 1822.37 | 1833.38 | 150.301036 | 151.209092 |
| 18 | AS/RS CART | 1914.59 | 1925.6 | 157.906935 | 158.814991 |
| 19 | AS/RS CART | 2005.98 | 2016.99 | 165.444378 | 166.352435 |
| 20 | AS/RS CART | 2111.21 | 2122.22 | 174.123285 | 175.031341 |
| 21 | AS/RS CART | 2293.37 | 2304.38 | 189.322282 | 190.230338 |
| 22 | AS/RS CART | 2581.25 | 2592.26 | 211.240599 | 212.148654 |
| 23 | AS/RS CART | 2689.37 | 2700.38 | 221.80737 | 222.715426 |
| 24 | MACHINE CENTER 2 | 2955.12 | 3202.848 | 235.477699 | 264.164852 |
| 25 | AS/RS CART | 2881.51 | 2892.52 | 237.654229 | 238.562288 |
| 26 | AS/RS CART | 3080.55 | 3091.56 | 254.894926 | 255.802982 |
| 27 | AS/RS CART | 3245.77 | 3256.78 | 267.696787 | 268.604843 |
| 28 | AS/RS CART | 3336.7 | 3347.71 | 275.196292 | 276.104348 |
| 29 | AS/RS CART | 3549.3 | 3560.31 | 292.730602 | 293.638658 |
| 30 | MACHINE CENTER 4 | 3670.76 | 3872.528 | 302.748087 | 319.339021 |
| 31 | AS/RS CART | 3806.6 | 3817.61 | 313.95157 | 314.859627 |
| 32 | AS/RS CART | 3849.08 | 3860.09 | 317.455133 | 318.36319 |
| 33 | MACHINE CENTER 5 | 3911.17 | 4440.832 | 322.576043 | 366.250227 |
| 34 | AS/RS CART | 3922.2 | 3933.21 | 323.485748 | 324.393805 |
| 35 | MINI-MOVER-5 | 3928.47 | 4115.898 | 324.00287 | 339.461105 |
| 36 | AS/RS CART | 4414.21 | 4425.22 | 364.064562 | 364.972618 |
| 37 | MACHINE CENTER 1 | 4578.37 | 4957.73 | 377.603754 | 408.892869 |
| 38 | AS/RS CART | 4649.39 | 4660.4 | 383.46117 | 384.369227 |
| 39 | AS/RS CART | 4694.17 | 4705.18 | 387.154427 | 388.062484 |
| 40 | AS/RS CART | 4769.2 | 4780.21 | 393.342571 | 394.250627 |
| 41 | AS/RS CART | 4845.47 | 4856.48 | 399.63041 | 400.728487 |
| 42 | AS/RS CART | 4890.33 | 4901.35 | 403.381725 | 404.269761 |
| 43 | AS/RS CART | 5243.37 | [illegible] | [illegible] | [illegible] |

| | | | | | |
|---|---|---|---|---|---|
| 44 | AS/RS CART | 5323.[illegible] | 5334.3 | 439.0327[illegible] | 439.950[illegible] |
| 45 | MACHINE CENTER 1 | 5349.26 | 5728.61 | 441.18336 | 472.470474 |
| 46 | AS/RS CART | 5385.14 | 5396.15 | 444.142584 | 445.05064 |
| 47 | MACHINE CENTER 2 | 5413.12 | 5760.946 | 446.450251 | 475.137404 |
| 48 | AS/RS CART | 5802.33 | 5813.39 | 482.05958 | 482.967837 |
| 49 | MINI-MOVER-5 | 5765.51 | 5952.938 | 475.513823 | 490.972057 |
| 50 | AS/RS CART | 5839.33 | 5850.34 | 481.602171 | 482.510227 |
| 51 | MACHINE CENTER 6 | 5850.19 | 6379.652 | 482.497856 | 526.16204 |
| 52 | AS/RS CART | 5954.63 | 5965.64 | 491.111606 | 492.019662 |
| 53 | MACHINE CENTER 3 | 5970.38 | 7160.058 | 492.408947 | 590.529388 |
| 54 | AS/RS CART | 6054.36 | 6065.37 | 499.338898 | 500.244953 |
| 55 | AS/RS CART | 6372.66 | 6383.67 | 525.586876 | 526.498932 |
| 56 | AS/RS CART | 6407.88 | 6418.89 | 528.493686 | 529.401722 |
| 57 | AS/RS CART | 6445.38 | 6456.39 | 531.536501 | 532.434557 |
| 58 | AS/RS CART | 6537.86 | 6548.87 | 539.197348 | 540.105404 |
| 58 | AS/RS CART | 6706.2 | 6717.21 | 553.097783 | 554.00584 |
| 60 | AS/RS CART | 6859.06 | 6870.03 | 565.706651 | 566.614707 |
| 61 | AS/RS CART | 6984.24 | 6995.25 | 576.029295 | 576.937351 |
| 62 | AS/RS CART | 7079.82 | 7090.83 | 583.912312 | 584.820363 |
| 63 | AS/RS CART | 7246.68 | 7257.69 | 597.674188 | 598.582245 |
| 64 | MINI-MOVER-5 | 7248.36 | 7435.786 | 597.812748 | 613.270982 |
| 65 | AS/RS CART | 7324.44 | 7335.45 | 604.08749 | 604.995546 |
| 66 | AS/RS CART | 7421.22 | 7432.23 | 612.069478 | 612.977534 |
| 67 | AS/RS CART | 7484.28 | 7495.29 | 617.270386 | 618.178444 |
| 68 | AS/RS CART | 7575 | 7586.01 | 624.752573 | 625.66063 |
| 69 | MINI-MOVER-5 | 7660.2 | 7947.628 | 631.779483 | 647.237723 |
| 70 | MACHINE CENTER 5 | 7686.12 | 8215.782 | 633.917261 | 677.601445 |
| 71 | AS/RS CART | 7744.68 | 7755.69 | 638.747031 | 639.655087 |
| 72 | AS/RS CART | 7847.34 | 7858.35 | 647.213975 | 648.122031 |
| 73 | AS/RS CART | 7891.56 | 7902.57 | 650.861045 | 651.769101 |
| 74 | AS/RS CART | 8046.16 | 8059.17 | 663.776722 | 664.684773 |
| 75 | AS/RS CART | 8340.66 | 8351.67 | 687.900831 | 688.808883 |

DECISION RULE SET= SPT/NINO
TIME SCALING FACTOR= 11.8468 ; SIMULATION TIME= 705.052234

| NO. | FAILED COMPONENT | ACTUAL FAILING TIME | ACTUAL RECOVERY TIME | ADJUSTED FAILING TIME | ADJUSTED RECOVERY TIME |
|---|---|---|---|---|---|
| 1 | AS/RS CART | 75.744 | 86.754 | 6.39362529 | 7.32298016 |
| 2 | AS/RS CART | 151.29 | 162.3 | 12.7705372 | 13.6998021 |
| 3 | AS/RS CART | 188.91 | 199.92 | 15.9460783 | 16.8754432 |
| 4 | AS/RS CART | 387.06 | 398.07 | 32.672114 | 33.6014789 |
| 5 | MINI-MOVER-5 | 567.336 | 754.764 | 47.8893879 | 63.710385 |
| 6 | AS/RS CART | 810.636 | 821.646 | 68.4265794 | 69.3559443 |
| 7 | AS/RS CART | 931.674 | 942.684 | 78.6435156 | 79.5728804 |
| 8 | AS/RS CART | 994.56 | 1005.57 | 83.9517845 | 84.8811494 |
| 9 | MACHINE CENTER 4 | 1038.47 | 1240.238 | 87.6582706 | 104.688705 |
| 10 | AS/RS CART | 1133.85 | 1144.86 | 95.717831 | 96.6471355 |
| 11 | AS/RS CART | 1255.36 | 1266.37 | 105.966163 | 106.895533 |
| 12 | AS/RS CART | 1292.76 | 1303.77 | 109.123138 | 110.052504 |
| 13 | AS/RS CART | 1344.59 | 1355.6 | 113.49816 | 114.427525 |
| 14 | AS/RS CART | 1386.1 | 1397.11 | 117.00206 | 117.931425 |
| 15 | AS/RS CART | 1551.55 | 1562.56 | 130.967856 | 131.897221 |
| 16 | AS/RS CART | 1720.57 | 1731.58 | 145.235 | 146.164365 |
| 17 | AS/RS CART | 1822.37 | 1833.38 | 153.828038 | 154.757403 |
| 18 | AS/RS CART | 1914.59 | 1925.6 | 161.612419 | 162.541784 |
| 19 | AS/RS CART | 2005.88 | 2016.89 | 169.326738 | 170.256103 |
| 20 | AS/RS CART | 2111.21 | 2122.22 | 178.209305 | 179.13867 |
| 21 | AS/RS CART | 2283.37 | 2294.38 | 192.7415 | 193.670865 |
| 22 | AS/RS CART | 2561.25 | 2572.26 | 216.197623 | 217.126988 |
| 23 | AS/RS CART | 2689.37 | 2700.38 | 227.012358 | 227.941723 |
| 24 | MACHINE CENTER 2 | 2855.12 | 3202.946 | 241.003478 | 270.363311 |
| 25 | AS/RS CART | 2881.51 | 2892.52 | 243.231084 | 244.160443 |
| 26 | AS/RS CART | 2990.55 | [illegible] | [illegible] | [illegible] |

| | | | | | |
|---|---|---|---|---|---|
| 27 | AS/RS CART | 3245.77 | 3256.78 | 273.978627 | 274.907992 |
| 28 | AS/RS CART | 3336.7 | 3347.71 | 281.654118 | 282.583483 |
| 29 | AS/RS CART | 3549.3 | 3560.31 | 299.599692 | 300.529257 |
| 30 | MACHINE CENTER 4 | 3670.78 | 3872.528 | 309.85245 | 326.983884 |
| 31 | AS/RS CART | 3806.8 | 3817.81 | 321.318837 | 322.248202 |
| 32 | AS/RS CART | 3849.08 | 3860.09 | 324.904618 | 325.833981 |
| 33 | MACHINE CENTER 5 | 3911.17 | 4440.832 | 330.145693 | 374.854882 |
| 34 | AS/RS CART | 3922.2 | 3933.21 | 331.070747 | 332.000111 |
| 35 | MINI-MOVER-5 | 3926.47 | 4115.698 | 331.606003 | 347.428984 |
| 36 | AS/RS CART | 4414.21 | 4425.22 | 372.607793 | 373.537158 |
| 37 | MACHINE CENTER 1 | 4578.37 | 4857.72 | 386.484898 | 410.486005 |
| 38 | AS/RS CART | 4649.39 | 4660.4 | 392.458587 | 393.388932 |
| 39 | AS/RS CART | 4694.17 | 4705.18 | 396.239491 | 397.168856 |
| 40 | AS/RS CART | 4769.2 | 4780.21 | 402.572647 | 403.502012 |
| 41 | AS/RS CART | 4848.47 | 4859.48 | 409.254105 | 410.18347 |
| 42 | AS/RS CART | 4890.06 | 4901.07 | 412.827093 | 413.756458 |
| 43 | AS/RS CART | 5246.07 | 5257.08 | 443.070703 | 444.000068 |
| 44 | AS/RS CART | 5323.79 | 5334.8 | 449.386332 | 450.315697 |
| 45 | MACHINE CENTER 1 | 5349.28 | 5726.81 | 451.53828 | 483.557585 |
| 46 | AS/RS CART | 5385.14 | 5396.15 | 454.564946 | 455.494311 |
| 47 | MACHINE CENTER 2 | 5413.12 | 5700.648 | 456.926705 | 480.287898 |
| 48 | AS/RS CART | 5602.36 | 5613.37 | 472.802387 | 473.731752 |
| 49 | MINI-MOVER-5 | 5765.51 | 5952.636 | 486.67235 | 502.403332 |
| 50 | AS/RS CART | 5835.33 | 5846.34 | 492.903569 | 493.832934 |
| 51 | MACHINE CENTER 6 | 5850.19 | 6378.852 | 493.620272 | 538.529501 |
| 52 | AS/RS CART | 5954.83 | 5965.84 | 502.636155 | 503.56552 |
| 53 | MACHINE CENTER 3 | 5970.36 | 7186.858 | 503.96384 | 604.387514 |
| 54 | AS/RS CART | 6054.36 | 6065.37 | 511.054462 | 511.983827 |
| 55 | AS/RS CART | 6372.86 | 6383.87 | 537.922477 | 538.851842 |
| 56 | AS/RS CART | 6407.88 | 6418.89 | 540.895432 | 541.824797 |
| 57 | AS/RS CART | 6445.38 | 6456.39 | 544.060844 | 544.990209 |
| 58 | AS/RS CART | 6537.86 | 6548.87 | 551.849289 | 552.778654 |
| 59 | AS/RS CART | 6706.2 | 6717.21 | 566.078916 | 567.00828 |
| 60 | AS/RS CART | 6859.66 | 6870.67 | 578.981666 | 579.911031 |
| 61 | AS/RS CART | 6884.24 | 6895.25 | 580.546545 | 581.475909 |
| 62 | AS/RS CART | 7070.82 | 7081.83 | 597.614546 | 598.543911 |
| 63 | AS/RS CART | 7246.86 | 7257.87 | 611.699362 | 612.628727 |
| 64 | MINI-MOVER-5 | 7248.38 | 7435.768 | 611.841173 | 627.862154 |
| 65 | AS/RS CART | 7324.44 | 7335.45 | 618.26318 | 619.192525 |
| 66 | AS/RS CART | 7421.22 | 7432.23 | 626.432454 | 627.361819 |
| 67 | AS/RS CART | 7484.28 | 7495.29 | 631.755411 | 632.684776 |
| 68 | AS/RS CART | 7575 | 7586.01 | 639.413175 | 640.34254 |
| 69 | MINI-MOVER-5 | 7660.2 | 7847.828 | 646.60489 | 662.425972 |
| 70 | MACHINE CENTER 5 | 7686.12 | 8215.782 | 648.792823 | 693.502212 |
| 71 | AS/RS CART | 7744.68 | 7755.69 | 653.73603 | 654.665395 |
| 72 | AS/RS CART | 7847.34 | 7858.35 | 662.401661 | 663.331026 |
| 73 | AS/RS CART | 7891.56 | 7902.57 | 666.134315 | 667.06368 |
| 74 | AS/RS CART | 8048.16 | 8059.17 | 679.353074 | 680.282439 |
| 75 | AS/RS CART | 8340.66 | 8351.67 | 704.043286 | 704.972651 |

DECISION RULE SET= SPT/WINQ
TIME SCALING FACTOR= 11.8828 : SIMULATION TIME= 718.988563

| NO. | FAILED COMPONENT | ACTUAL FAILING TIME | ACTUAL RECOVERY TIME | ADJUSTED FAILING TIME | ADJUSTED RECOVERY TIME |
|---|---|---|---|---|---|
| 1 | AS/RS CART | 75.744 | 86.754 | 6.48332178 | 7.42572478 |
| 2 | AS/RS CART | 151.29 | 162.3 | 12.8486957 | 13.8920387 |
| 3 | AS/RS CART | 188.91 | 199.92 | 16.1897866 | 17.1121836 |
| 4 | AS/RS CART | 387.06 | 398.07 | 33.1304728 | 34.0728757 |
| 5 | MINI-MOVER-5 | 567.336 | 754.764 | 48.5612305 | 64.6041651 |
| 6 | AS/RS CART | 810.636 | 821.646 | 69.3865393 | 70.3289423 |
| 7 | AS/RS CART | 931.674 | 942.684 | 79.7468095 | 80.6892124 |
| 8 | AS/RS CART | 994.56 | 1005.57 | 85.1295483 | 86.0719513 |
| 9 | MACHINE CENTER 4 | 1038.47 | 1240.238 | 88.888033 | 106.158403 |
| 10 | AS/RS CART | 1133.95 | 1144.96 | 97.0606613 | 98.0030643 |

| | | | | | |
|---|---|---|---|---|---|
| 11 | AS/RS CART | 1255.36 | 1266.37 | 107.452772 | 108.395176 |
| 12 | AS/RS CART | 1292.76 | 1303.77 | 110.654033 | 111.596436 |
| 13 | AS/RS CART | 1344.59 | 1355.6 | 115.090431 | 116.032834 |
| 14 | AS/RS CART | 1386.1 | 1397.11 | 118.643488 | 119.585891 |
| 15 | AS/RS CART | 1551.55 | 1562.56 | 132.805211 | 133.747614 |
| 16 | AS/RS CART | 1720.57 | 1731.58 | 147.272509 | 148.214912 |
| 17 | AS/RS CART | 1822.37 | 1833.38 | 155.986099 | 156.928502 |
| 18 | AS/RS CART | 1914.59 | 1925.6 | 163.879687 | 164.82209 |
| 19 | AS/RS CART | 2005.98 | 2016.99 | 171.702231 | 172.644635 |
| 20 | AS/RS CART | 2111.21 | 2122.22 | 180.709413 | 181.651816 |
| 21 | AS/RS CART | 2283.37 | 2294.38 | 195.44548 | 196.387883 |
| 22 | AS/RS CART | 2561.25 | 2572.26 | 219.230671 | 220.173074 |
| 23 | AS/RS CART | 2689.37 | 2700.38 | 230.197126 | 231.139529 |
| 24 | MACHINE CENTER 2 | 2855.12 | 3202.946 | 244.384528 | 274.158759 |
| 25 | AS/RS CART | 2881.51 | 2892.52 | 246.643385 | 247.585788 |
| 26 | AS/RS CART | 3090.55 | 3101.56 | 264.536203 | 265.478606 |
| 27 | AS/RS CART | 3245.77 | 3256.78 | 277.822287 | 278.76469 |
| 28 | AS/RS CART | 3336.7 | 3347.71 | 285.605458 | 286.547861 |
| 29 | AS/RS CART | 3549.3 | 3560.31 | 303.802994 | 304.745397 |
| 30 | MACHINE CENTER 4 | 3670.76 | 3872.528 | 314.189386 | 331.469755 |
| 31 | AS/RS CART | 3806.8 | 3817.81 | 325.826636 | 326.769039 |
| 32 | AS/RS CART | 3849.08 | 3860.09 | 329.462719 | 330.405122 |
| 33 | MACHINE CENTER 5 | 3911.17 | 4440.832 | 334.777324 | 380.113842 |
| 34 | AS/RS CART | 3922.2 | 3933.21 | 335.721439 | 336.663842 |
| 35 | MINI-MOVER-5 | 3928.47 | 4115.898 | 336.258121 | 352.301055 |
| 36 | AS/RS CART | 4414.21 | 4425.22 | 377.835127 | 378.77753 |
| 37 | MACHINE CENTER 1 | 4573.37 | 4957.72 | 391.886432 | 424.356968 |
| 38 | AS/RS CART | 4649.39 | 4660.4 | 397.865402 | 398.807805 |
| 39 | AS/RS CART | 4694.17 | 4705.18 | 401.798355 | 402.740758 |
| 40 | AS/RS CART | 4769.2 | 4780.21 | 408.220562 | 409.162965 |
| 41 | AS/RS CART | 4848.47 | 4859.48 | 415.005692 | 415.948095 |
| 42 | AS/RS CART | 4890.68 | 4901.69 | 418.618665 | 419.561068 |
| 43 | AS/RS CART | 5248.87 | 5259.88 | 449.286534 | 450.228937 |
| 44 | AS/RS CART | 5323.79 | 5334.8 | 455.690736 | 456.633139 |
| 45 | MACHINE CENTER 1 | 5349.26 | 5728.61 | 457.870905 | 490.341436 |
| 46 | AS/RS CART | 5385.14 | 5396.15 | 460.942061 | 461.884463 |
| 47 | MACHINE CENTER 2 | 5413.12 | 5760.946 | 463.337014 | 493.109245 |
| 48 | AS/RS CART | 5602.38 | 5613.39 | 479.536759 | 480.479162 |
| 49 | MINI-MOVER-5 | 5765.51 | 5952.938 | 493.499502 | 509.542836 |
| 50 | AS/RS CART | 5839.33 | 5850.34 | 499.818538 | 500.760941 |
| 51 | MACHINE CENTER 6 | 5850.19 | 6379.852 | 500.748102 | 546.084613 |
| 52 | AS/RS CART | 5954.63 | 5965.64 | 509.687663 | 510.630066 |
| 53 | MACHINE CENTER 3 | 5970.36 | 7160.058 | 511.034076 | 612.866437 |
| 54 | AS/RS CART | 6054.36 | 6065.37 | 518.224071 | 519.166474 |
| 55 | AS/RS CART | 6372.66 | 6383.67 | 545.469019 | 546.411422 |
| 56 | AS/RS CART | 6407.88 | 6418.89 | 548.483681 | 549.426084 |
| 57 | AS/RS CART | 6445.38 | 6456.39 | 551.693501 | 552.635904 |
| 58 | AS/RS CART | 6537.66 | 6548.67 | 559.592225 | 560.534628 |
| 59 | AS/RS CART | 6706.2 | 6717.21 | 574.018437 | 574.96084 |
| 60 | AS/RS CART | 6859.08 | 6870.09 | 587.104229 | 588.046632 |
| 61 | AS/RS CART | 6984.24 | 6995.25 | 597.817323 | 598.759726 |
| 62 | AS/RS CART | 7079.82 | 7090.83 | 605.998511 | 606.940914 |
| 63 | AS/RS CART | 7246.68 | 7257.69 | 620.280923 | 621.223326 |
| 64 | MINI-MOVER-5 | 7248.36 | 7435.788 | 620.424724 | 636.467658 |
| 65 | AS/RS CART | 7324.44 | 7335.45 | 626.936905 | 627.879308 |
| 66 | AS/RS CART | 7421.22 | 7432.23 | 635.220707 | 636.16311 |
| 67 | AS/RS CART | 7484.28 | 7495.29 | 640.61834 | 641.560743 |
| 68 | AS/RS CART | 7575 | 7586.01 | 648.383535 | 649.325938 |
| 69 | MINI-MOVER-5 | 7660.2 | 7847.628 | 655.676245 | 671.719179 |
| 70 | MACHINE CENTER 5 | 7686.12 | 8215.782 | 657.894872 | 703.23139 |
| 71 | AS/RS CART | 7744.68 | 7755.69 | 662.907326 | 663.849729 |
| 72 | AS/RS CART | 7847.34 | 7858.35 | 671.694528 | 672.636931 |
| 73 | AS/RS CART | 7891.56 | 7902.57 | 675.479547 | 676.42195 |
| 74 | AS/RS CART | 8048.16 | 8059.17 | 688.883753 | 689.826156 |
| 75 | AS/RS CART | 8340.65 | 8351.67 | 713.920345 | 714.862748 |

DECISION RULE SET= DDATE/RANDOM
TIME SCALING FACTOR= 11.8578 ; SIMULATION TIME= 708.406423

| NO. | FAILED COMPONENT | ACTUAL FAILING TIME | ACTUAL RECOVERY TIME | ADJUSTED FAILING TIME | ADJUSTED RECOVERY TIME |
|---|---|---|---|---|---|
| 1 | AS/RS CART | 75.744 | 86.754 | 6.38790192 | 7.31632034 |
| 2 | AS/RS CART | 151.29 | 162.3 | 12.7589057 | 13.6874241 |
| 3 | AS/RS CART | 188.91 | 199.92 | 15.9315544 | 16.8600729 |
| 4 | AS/RS CART | 387.06 | 398.07 | 32.642358 | 33.5708744 |
| 5 | MINI-MOVER-5 | 587.338 | 754.764 | 47.8457698 | 63.6523411 |
| 6 | AS/RS CART | 810.636 | 821.646 | 68.3642559 | 69.2927743 |
| 7 | AS/RS CART | 931.674 | 942.684 | 78.5718864 | 79.5004048 |
| 8 | AS/RS CART | 994.56 | 1005.57 | 83.8753205 | 84.8038383 |
| 9 | MACHINE CENTER 4 | 1038.47 | 1240.239 | 87.5784308 | 104.594353 |
| 10 | AS/RS CART | 1133.85 | 1144.86 | 95.6208504 | 96.5531689 |
| 11 | AS/RS CART | 1255.36 | 1266.37 | 105.869653 | 106.798172 |
| 12 | AS/RS CART | 1292.76 | 1303.77 | 109.023748 | 109.952287 |
| 13 | AS/RS CART | 1344.59 | 1355.6 | 113.394785 | 114.323303 |
| 14 | AS/RS CART | 1386.1 | 1397.11 | 116.895493 | 117.824012 |
| 15 | AS/RS CART | 1551.55 | 1562.56 | 130.84857 | 131.777068 |
| 16 | AS/RS CART | 1720.57 | 1731.58 | 145.102718 | 146.031237 |
| 17 | AS/RS CART | 1822.37 | 1833.38 | 153.68793 | 154.616449 |
| 18 | AS/RS CART | 1914.59 | 1925.6 | 161.465221 | 162.393739 |
| 19 | AS/RS CART | 2005.98 | 2016.99 | 169.172514 | 170.101032 |
| 20 | AS/RS CART | 2111.21 | 2122.22 | 178.046931 | 178.97551 |
| 21 | AS/RS CART | 2283.37 | 2294.38 | 192.565949 | 193.494468 |
| 22 | AS/RS CART | 2561.25 | 2572.26 | 216.000709 | 216.929227 |
| 23 | AS/RS CART | 2689.37 | 2700.38 | 226.805583 | 227.734112 |
| 24 | MACHINE CENTER 2 | 2855.12 | 3202.846 | 240.78397 | 270.117582 |
| 25 | AS/RS CART | 2881.51 | 2892.52 | 243.009547 | 243.938065 |
| 26 | AS/RS CART | 3090.55 | 3101.56 | 260.638747 | 261.567255 |
| 27 | AS/RS CART | 3245.77 | 3256.78 | 273.728085 | 274.657604 |
| 28 | AS/RS CART | 3336.7 | 3347.71 | 281.397585 | 282.326103 |
| 29 | AS/RS CART | 3549.3 | 3560.31 | 299.327014 | 300.255533 |
| 30 | MACHINE CENTER 4 | 3670.76 | 3872.528 | 309.570234 | 326.586158 |
| 31 | AS/RS CART | 3806.6 | 3817.61 | 321.026178 | 321.954696 |
| 32 | AS/RS CART | 3849.08 | 3860.09 | 324.60869 | 325.537208 |
| 33 | MACHINE CENTER 5 | 3911.17 | 4440.832 | 329.844884 | 374.513561 |
| 34 | AS/RS CART | 3922.2 | 3933.21 | 330.775199 | 331.703718 |
| 35 | MINI-MOVER-5 | 3928.47 | 4115.898 | 331.303874 | 347.110545 |
| 36 | AS/RS CART | 4414.21 | 4425.22 | 372.268419 | 373.196937 |
| 37 | MACHINE CENTER 1 | 4578.37 | 4957.72 | 386.112704 | 418.104844 |
| 38 | AS/RS CART | 4649.39 | 4660.4 | 392.102112 | 393.03063 |
| 39 | AS/RS CART | 4694.17 | 4705.18 | 395.878593 | 396.807111 |
| 40 | AS/RS CART | 4769.2 | 4780.21 | 402.20618 | 403.134699 |
| 41 | AS/RS CART | 4848.47 | 4859.48 | 408.891344 | 409.819863 |
| 42 | AS/RS CART | 4890.66 | 4901.68 | 412.451086 | 413.379605 |
| 43 | AS/RS CART | 5248.97 | 5259.98 | 442.66715 | 443.595669 |
| 44 | AS/RS CART | 5323.79 | 5334.8 | 448.977028 | 449.905546 |
| 45 | MACHINE CENTER 1 | 5349.26 | 5728.61 | 451.125017 | 483.117157 |
| 46 | AS/RS CART | 5385.14 | 5396.15 | 454.150925 | 455.079443 |
| 47 | MACHINE CENTER 2 | 5413.12 | 5760.946 | 456.510593 | 485.844185 |
| 48 | AS/RS CART | 5602.38 | 5613.39 | 472.471664 | 473.400183 |
| 49 | MINI-MOVER-5 | 5765.51 | 5952.338 | 486.229086 | 502.035637 |
| 50 | AS/RS CART | 5839.33 | 5850.34 | 492.454628 | 493.383147 |
| 51 | MACHINE CENTER 6 | 5850.19 | 6379.852 | 493.370437 | 538.039064 |
| 52 | AS/RS CART | 5954.63 | 5965.64 | 502.17835 | 503.106869 |
| 53 | MACHINE CENTER 3 | 5970.38 | 7180.059 | 503.504325 | 605.537033 |
| 54 | AS/RS CART | 6054.36 | 6065.37 | 510.58898 | 511.517508 |
| 55 | AS/RS CART | 6372.66 | 6383.67 | 537.432533 | 538.361051 |
| 56 | AS/RS CART | 6407.88 | 6418.89 | 540.40278 | 541.331298 |
| 57 | AS/RS CART | 6445.32 | 6456.33 | 543.565309 | 544.493827 |
| 58 | AS/RS CART | 6537.66 | 6548.67 | 551.347639 | 552.276178 |
| 59 | AS/RS CART | 6706.3 | 6717.31 | 565.56[illegible] | 566.48[illegible] |

| | | | | | |
|---|---|---|---|---|---|
| 60 | AS/RS CART | 6859.08 | 6870.09 | 573.454325 | 574.382343 |
| 61 | AS/RS CART | 6984.24 | 6995.25 | 589.009581 | 589.938099 |
| 62 | AS/RS CART | 7079.82 | 7090.83 | 597.070234 | 597.998752 |
| 63 | AS/RS CART | 7246.88 | 7257.89 | 611.142221 | 612.07074 |
| 64 | MINI-MOVER-5 | 7248.38 | 7435.768 | 611.283903 | 627.080474 |
| 65 | AS/RS CART | 7324.44 | 7335.45 | 617.700041 | 618.628559 |
| 66 | AS/RS CART | 7421.22 | 7432.23 | 625.861895 | 626.790413 |
| 67 | AS/RS CART | 7484.28 | 7495.29 | 631.180003 | 632.108521 |
| 68 | AS/RS CART | 7575 | 7586.01 | 638.830792 | 639.759311 |
| 69 | MINI-MOVER-5 | 7660.2 | 7847.628 | 646.016058 | 661.822629 |
| 70 | MACHINE CENTER 5 | 7666.12 | 8215.782 | 646.201897 | 692.678565 |
| 71 | AS/RS CART | 7744.68 | 7755.69 | 653.140602 | 654.069121 |
| 72 | AS/RS CART | 7847.34 | 7858.35 | 661.788341 | 662.728659 |
| 73 | AS/RS CART | 7881.56 | 7892.57 | 665.527585 | 666.456113 |
| 74 | AS/RS CART | 8048.16 | 8059.17 | 678.734314 | 679.662832 |
| 75 | AS/RS CART | 8340.86 | 8351.87 | 703.402038 | 704.330556 |

DECISION RULE SET= DDATE/FMFS
TIME SCALING FACTOR= 11.9675 ; SIMULATION TIME= 701.800882

| NO. | FAILED COMPONENT | ACTUAL FAILING TIME | ACTUAL RECOVERY TIME | ADJUSTED FAILING TIME | ADJUSTED RECOVERY TIME |
|---|---|---|---|---|---|
| 1 | AS/RS CART | 75.744 | 86.754 | 6.32814143 | 7.24613367 |
| 2 | AS/RS CART | 151.29 | 162.3 | 12.641736 | 13.5617287 |
| 3 | AS/RS CART | 188.81 | 199.82 | 15.7852517 | 16.7052434 |
| 4 | AS/RS CART | 387.06 | 398.07 | 32.3425845 | 33.2625862 |
| 5 | MINI-MOVER-5 | 567.336 | 754.764 | 47.4063923 | 63.0678087 |
| 6 | AS/RS CART | 810.836 | 821.846 | 67.7364529 | 68.6564446 |
| 7 | AS/RS CART | 931.674 | 942.684 | 77.8503447 | 78.7703363 |
| 8 | AS/RS CART | 994.56 | 1005.57 | 83.1056763 | 84.0256679 |
| 9 | MACHINE CENTER 4 | 1038.47 | 1240.236 | 86.7741801 | 103.633842 |
| 10 | AS/RS CART | 1133.85 | 1144.86 | 94.7524545 | 95.6724463 |
| 11 | AS/RS CART | 1255.36 | 1266.37 | 104.897431 | 105.817422 |
| 12 | AS/RS CART | 1292.76 | 1303.77 | 108.022561 | 108.942553 |
| 13 | AS/RS CART | 1344.59 | 1355.6 | 112.353457 | 113.273448 |
| 14 | AS/RS CART | 1386.1 | 1397.11 | 115.822016 | 116.74201 |
| 15 | AS/RS CART | 1551.55 | 1562.56 | 129.646861 | 130.566852 |
| 16 | AS/RS CART | 1720.57 | 1731.58 | 143.770211 | 144.690203 |
| 17 | AS/RS CART | 1822.37 | 1833.38 | 152.276582 | 153.196574 |
| 18 | AS/RS CART | 1914.59 | 1925.6 | 159.982452 | 160.902444 |
| 19 | AS/RS CART | 2005.98 | 2016.99 | 167.618868 | 168.53886 |
| 20 | AS/RS CART | 2111.21 | 2122.22 | 176.411648 | 177.331641 |
| 21 | AS/RS CART | 2283.37 | 2294.38 | 190.797577 | 191.717568 |
| 22 | AS/RS CART | 2561.25 | 2572.26 | 214.01713 | 214.937121 |
| 23 | AS/RS CART | 2689.37 | 2700.38 | 224.722791 | 225.642783 |
| 24 | MACHINE CENTER 2 | 2855.12 | 3202.946 | 238.572801 | 267.637017 |
| 25 | AS/RS CART | 2881.51 | 2892.52 | 240.77794 | 241.697932 |
| 26 | AS/RS CART | 3090.55 | 3101.56 | 258.245248 | 259.165239 |
| 27 | AS/RS CART | 3245.77 | 3256.78 | 271.215375 | 272.135367 |
| 28 | AS/RS CART | 3336.7 | 3347.71 | 278.813453 | 279.733445 |
| 29 | AS/RS CART | 3549.3 | 3560.31 | 296.578233 | 297.498224 |
| 30 | MACHINE CENTER 4 | 3670.76 | 3872.528 | 306.727387 | 323.587048 |
| 31 | AS/RS CART | 3806.6 | 3817.61 | 318.078128 | 318.99812 |
| 32 | AS/RS CART | 3849.08 | 3860.09 | 321.627742 | 322.547733 |
| 33 | MACHINE CENTER 5 | 3911.17 | 4440.832 | 326.81586 | 371.074326 |
| 34 | AS/RS CART | 3922.2 | 3933.21 | 327.737623 | 328.657614 |
| 35 | MINI-MOVER-5 | 3928.47 | 4115.898 | 328.261542 | 343.922858 |
| 36 | AS/RS CART | 4414.21 | 4425.22 | 368.849802 | 369.769793 |
| 37 | MACHINE CENTER 1 | 4578.37 | 4957.72 | 382.566852 | 414.265302 |
| 38 | AS/RS CART | 4649.39 | 4660.4 | 388.501358 | 389.42135 |
| 39 | AS/RS CART | 4694.17 | 4705.18 | 392.243158 | 393.16315 |
| 40 | AS/RS CART | 4769.2 | 4780.21 | 398.512639 | 399.43263 |
| 41 | AS/RS CART | 4848.47 | 4859.48 | 405.136411 | 406.056403 |
| 42 | AS/RS CART | 4890.68 | 4901.69 | 408.663463 | 409.583455 |

| | | | | | |
|---|---|---|---|---|---|
| 43 | AS/RS CART | 5248.37 | 5259.38 | 433.602047 | 433.522[illegible] |
| 44 | AS/RS CART | 5323.79 | 5334.8 | 444.353373 | 445.77397[illegible] |
| 45 | MACHINE CENTER 1 | 5349.26 | 5728.61 | 446.988244 | 478.680593 |
| 46 | AS/RS CART | 5385.14 | 5396.15 | 449.980383 | 450.900355 |
| 47 | MACHINE CENTER 2 | 5413.12 | 5780.946 | 452.318362 | 481.382578 |
| 48 | AS/RS CART | 5602.39 | 5613.39 | 468.13288 | 469.052852 |
| 49 | MINI-MOVER-5 | 5785.51 | 5952.938 | 481.763944 | 497.42536 |
| 50 | AS/RS CART | 5839.33 | 5850.34 | 487.932317 | 488.852308 |
| 51 | MACHINE CENTER 6 | 5850.19 | 6379.652 | 486.839774 | 533.098141 |
| 52 | AS/RS CART | 5954.63 | 5965.64 | 497.566743 | 498.486735 |
| 53 | MACHINE CENTER 3 | 5970.38 | 7160.058 | 498.881137 | 598.291874 |
| 54 | AS/RS CART | 6054.38 | 6065.37 | 505.900146 | 506.820138 |
| 55 | AS/RS CART | 6372.66 | 6383.67 | 532.49718 | 533.417172 |
| 56 | AS/RS CART | 6407.88 | 6418.89 | 535.44015 | 536.360142 |
| 57 | AS/RS CART | 6445.38 | 6456.39 | 538.573837 | 539.493829 |
| 58 | AS/RS CART | 6537.86 | 6548.87 | 546.284521 | 547.204512 |
| 59 | AS/RS CART | 6706.2 | 6717.21 | 560.367663 | 561.287654 |
| 60 | AS/RS CART | 6859.08 | 6870.09 | 573.14226 | 574.062252 |
| 61 | AS/RS CART | 6984.24 | 6995.25 | 583.600585 | 584.520578 |
| 62 | AS/RS CART | 7079.82 | 7090.83 | 591.587215 | 592.507207 |
| 63 | AS/RS CART | 7246.68 | 7257.69 | 605.529377 | 606.449369 |
| 64 | MINI-MOVER-5 | 7249.36 | 7435.788 | 605.870358 | 621.331773 |
| 65 | AS/RS CART | 7324.44 | 7335.45 | 612.027575 | 612.947566 |
| 66 | AS/RS CART | 7421.22 | 7432.23 | 620.114477 | 621.034469 |
| 67 | AS/RS CART | 7484.28 | 7495.29 | 625.383748 | 626.303739 |
| 68 | AS/RS CART | 7575 | 7586.01 | 632.964278 | 633.88427 |
| 69 | MINI-MOVER-5 | 7660.2 | 7847.628 | 640.08356 | 655.744976 |
| 70 | MACHINE CENTER 5 | 7686.12 | 8215.782 | 642.249428 | 686.507792 |
| 71 | AS/RS CART | 7744.68 | 7755.69 | 647.142678 | 648.06267 |
| 72 | AS/RS CART | 7847.34 | 7858.35 | 655.720811 | 656.640802 |
| 73 | AS/RS CART | 7891.56 | 7902.57 | 659.415918 | 660.33591 |
| 74 | AS/RS CART | 8048.18 | 8059.17 | 672.501358 | 673.42135 |
| 75 | AS/RS CART | 8340.66 | 8351.67 | 696.942553 | 697.862544 |

DECISION RULE SET= DDATE/NINQ
TIME SCALING FACTOR= 11.7589 ; SIMULATION TIME= 714.352533

| NO. | FAILED COMPONENT | ACTUAL FAILING TIME | ACTUAL RECOVERY TIME | ADJUSTED FAILING TIME | ADJUSTED RECOVERY TIME |
|---|---|---|---|---|---|
| 1 | AS/RS CART | 75.744 | 86.754 | 6.44141884 | 7.37773091 |
| 2 | AS/RS CART | 151.28 | 162.3 | 12.8658884 | 13.8023114 |
| 3 | AS/RS CART | 188.91 | 199.92 | 16.0652782 | 17.0015903 |
| 4 | AS/RS CART | 387.06 | 398.07 | 32.9163442 | 33.8528563 |
| 5 | MINI-MOVER-5 | 567.336 | 754.764 | 48.2473701 | 64.1866161 |
| 6 | AS/RS CART | 810.636 | 821.646 | 68.9380809 | 69.874393 |
| 7 | AS/RS CART | 931.674 | 942.684 | 79.2313906 | 80.1677027 |
| 8 | AS/RS CART | 994.56 | 1005.57 | 84.5793398 | 85.515652 |
| 9 | MACHINE CENTER 4 | 1038.47 | 1240.238 | 88.3135328 | 105.472231 |
| 10 | AS/RS CART | 1133.85 | 1144.86 | 96.4333398 | 97.3696519 |
| 11 | AS/RS CART | 1255.36 | 1266.37 | 106.758285 | 107.694397 |
| 12 | AS/RS CART | 1292.76 | 1303.77 | 109.938855 | 110.875167 |
| 13 | AS/RS CART | 1344.59 | 1355.6 | 114.34659 | 115.282902 |
| 14 | AS/RS CART | 1386.1 | 1397.11 | 117.876672 | 118.812984 |
| 15 | AS/RS CART | 1551.55 | 1562.56 | 131.946866 | 132.883178 |
| 16 | AS/RS CART | 1720.57 | 1731.58 | 146.320659 | 147.256971 |
| 17 | AS/RS CART | 1822.37 | 1833.38 | 154.977932 | 155.914244 |
| 18 | AS/RS CART | 1914.59 | 1925.6 | 162.820502 | 163.756814 |
| 19 | AS/RS CART | 2005.98 | 2016.99 | 170.592487 | 171.5289 |
| 20 | AS/RS CART | 2111.21 | 2122.22 | 179.541454 | 180.477766 |
| 21 | AS/RS CART | 2283.37 | 2294.38 | 194.182279 | 195.118591 |
| 22 | AS/RS CART | 2561.25 | 2572.26 | 217.813741 | 218.750053 |
| 23 | AS/RS CART | 2689.37 | 2700.38 | 228.709318 | 229.64563 |
| 24 | MACHINE CENTER 2 | 2855.12 | 3202.946 | 242.805234 | 272.384832 |
| 25 | AS/RS CART | 2881.51 | 2892.52 | 245.049232 | 245.985544 |
| 26 | AS/RS CART | 3090.55 | 3101.56 | 262.826455 | 263.762767 |

| | | | | | |
|---|---|---|---|---|---|
| 27 | AS/RS CART | 3245.77 | 3256.73 | 279.626683 | 280.56[illegible] |
| 28 | AS/RS CART | 3336.7 | 3347.71 | 283.753535 | 284.690647 |
| 29 | AS/RS CART | 3549.3 | 3560.31 | 301.839458 | 302.77577 |
| 30 | MACHINE CENTER 4 | 3670.76 | 3872.528 | 312.168655 | 329.327403 |
| 31 | AS/RS CART | 3806.6 | 3817.61 | 323.720758 | 324.657068 |
| 32 | AS/RS CART | 3849.08 | 3860.09 | 327.333339 | 328.269651 |
| 33 | MACHINE CENTER 5 | 3911.17 | 4440.832 | 332.613595 | 377.657034 |
| 34 | AS/RS CART | 3922.2 | 3933.21 | 333.551608 | 334.48792 |
| 35 | MINI-MOVER-5 | 3928.47 | 4115.898 | 334.084821 | 350.024067 |
| 36 | AS/RS CART | 4414.21 | 4425.22 | 375.393107 | 376.329419 |
| 37 | MACHINE CENTER 1 | 4578.37 | 4957.72 | 389.353598 | 421.614268 |
| 38 | AS/RS CART | 4649.39 | 4660.4 | 395.393276 | 396.329588 |
| 39 | AS/RS CART | 4694.17 | 4705.18 | 399.201456 | 400.137768 |
| 40 | AS/RS CART | 4769.2 | 4780.21 | 405.582155 | 406.518467 |
| 41 | AS/RS CART | 4848.47 | 4859.48 | 412.323431 | 413.259744 |
| 42 | AS/RS CART | 4890.68 | 4901.69 | 415.913053 | 416.849365 |
| 43 | AS/RS CART | 5248.97 | 5259.98 | 446.38274 | 447.319052 |
| 44 | AS/RS CART | 5323.79 | 5334.8 | 452.74558 | 453.681892 |
| 45 | MACHINE CENTER 1 | 5349.26 | 5728.61 | 454.911593 | 487.172289 |
| 46 | AS/RS CART | 5385.14 | 5396.15 | 457.962905 | 458.899216 |
| 47 | MACHINE CENTER 2 | 5413.12 | 5760.848 | 460.342379 | 489.922186 |
| 48 | AS/RS CART | 5602.38 | 5613.39 | 476.437422 | 477.373734 |
| 49 | MINI-MOVER-5 | 5785.51 | 5952.938 | 480.310318 | 506.249564 |
| 50 | AS/RS CART | 5839.33 | 5850.34 | 496.588116 | 497.524428 |
| 51 | MACHINE CENTER 6 | 5850.19 | 6379.852 | 497.511872 | 542.555171 |
| 52 | AS/RS CART | 5954.63 | 5965.64 | 506.393455 | 507.329767 |
| 53 | MACHINE CENTER 3 | 5970.36 | 7160.058 | 507.731165 | 608.905425 |
| 54 | AS/RS CART | 6054.36 | 6065.37 | 514.874691 | 515.811003 |
| 55 | AS/RS CART | 6372.66 | 6383.67 | 541.943549 | 542.879861 |
| 56 | AS/RS CART | 6407.88 | 6418.89 | 544.938727 | 545.875039 |
| 57 | AS/RS CART | 6445.38 | 6456.39 | 548.127801 | 549.064113 |
| 58 | AS/RS CART | 6537.66 | 6548.67 | 555.975474 | 556.911786 |
| 59 | AS/RS CART | 6706.2 | 6717.21 | 570.308447 | 571.244759 |
| 60 | AS/RS CART | 6859.06 | 6870.08 | 583.309663 | 584.245975 |
| 61 | AS/RS CART | 6984.24 | 6995.25 | 593.953516 | 594.889829 |
| 62 | AS/RS CART | 7079.82 | 7090.83 | 602.081827 | 603.01814 |
| 63 | AS/RS CART | 7246.88 | 7257.89 | 616.27193 | 617.208242 |
| 64 | MINI-MOVER-5 | 7248.36 | 7435.788 | 616.414801 | 632.354047 |
| 65 | AS/RS CART | 7324.44 | 7335.45 | 622.884793 | 623.821105 |
| 66 | AS/RS CART | 7421.22 | 7432.23 | 631.115155 | 632.051467 |
| 67 | AS/RS CART | 7484.28 | 7495.29 | 636.477901 | 637.414214 |
| 68 | AS/RS CART | 7575 | 7586.01 | 644.192909 | 645.129221 |
| 69 | MINI-MOVER-5 | 7660.2 | 7847.628 | 651.438485 | 667.377731 |
| 70 | MACHINE CENTER 5 | 7686.12 | 8215.782 | 653.642773 | 698.686272 |
| 71 | AS/RS CART | 7744.88 | 7755.89 | 658.62283 | 659.559142 |
| 72 | AS/RS CART | 7847.34 | 7858.35 | 667.353238 | 668.289551 |
| 73 | AS/RS CART | 7891.56 | 7902.57 | 671.113785 | 672.050107 |
| 74 | AS/RS CART | 8048.16 | 8059.17 | 684.431367 | 685.367679 |
| 75 | AS/RS CART | 8340.66 | 8351.67 | 709.306143 | 710.242454 |

DECISION RULE SET= ODATE/WINQ
TIME SCALING FACTOR= 11.6064 : SIMULATION TIME= 723.738627

| NO. | FAILED COMPONENT | ACTUAL FAILING TIME | ACTUAL RECOVERY TIME | ADJUSTED FAILING TIME | ADJUSTED RECOVERY TIME |
|---|---|---|---|---|---|
| 1 | AS/RS CART | 75.744 | 86.754 | 6.52605459 | 7.47466815 |
| 2 | AS/RS CART | 151.29 | 162.3 | 13.0350498 | 13.9836642 |
| 3 | AS/RS CART | 188.91 | 199.92 | 16.2763843 | 17.2249793 |
| 4 | AS/RS CART | 387.06 | 398.07 | 33.348842 | 34.2974565 |
| 5 | MINI-MOVER-5 | 567.336 | 754.764 | 48.8813068 | 65.0298834 |
| 6 | AS/RS CART | 810.636 | 821.646 | 69.8438792 | 70.7924938 |
| 7 | AS/RS CART | 931.674 | 942.684 | 80.2724359 | 81.2210504 |
| 8 | AS/RS CART | 994.56 | 1005.57 | 85.6906534 | 86.639266 |
| 9 | MACHINE CENTER 4 | [illegible] | 1240.233 | [illegible] | [illegible] |
| 10 | AS/RS CART | 1133.35 | 1144.36 | [illegible] | [illegible] |

| | | | | | |
|---|---|---|---|---|---|
| 11 | AS/RS CART | 1255.36 | 1266.37 | 105.161015 | 106.105669 |
| 12 | AS/RS CART | 1292.76 | 1303.77 | 111.333375 | 112.331239 |
| 13 | AS/RS CART | 1344.59 | 1355.6 | 115.849014 | 116.797628 |
| 14 | AS/RS CART | 1386.1 | 1397.11 | 119.425489 | 120.374104 |
| 15 | AS/RS CART | 1551.55 | 1562.56 | 133.680556 | 134.62917 |
| 16 | AS/RS CART | 1720.57 | 1731.58 | 148.243211 | 149.191825 |
| 17 | AS/RS CART | 1822.37 | 1833.38 | 157.014234 | 157.962848 |
| 18 | AS/RS CART | 1914.59 | 1925.6 | 164.95985 | 165.908464 |
| 19 | AS/RS CART | 2005.98 | 2016.99 | 172.833954 | 173.782568 |
| 20 | AS/RS CART | 2111.21 | 2122.22 | 181.900503 | 182.849118 |
| 21 | AS/RS CART | 2283.37 | 2294.38 | 196.733699 | 197.682313 |
| 22 | AS/RS CART | 2561.25 | 2572.26 | 220.675662 | 221.624276 |
| 23 | AS/RS CART | 2689.37 | 2700.38 | 231.714399 | 232.663013 |
| 24 | MACHINE CENTER 2 | 2855.12 | 3202.946 | 245.985313 | 275.983779 |
| 25 | AS/RS CART | 2881.51 | 2892.52 | 248.268058 | 249.217873 |
| 26 | AS/RS CART | 3080.55 | 3101.56 | 266.279811 | 267.228426 |
| 27 | AS/RS CART | 3245.77 | 3256.78 | 279.653487 | 280.602081 |
| 28 | AS/RS CART | 3336.7 | 3347.71 | 287.487836 | 288.436532 |
| 29 | AS/RS CART | 3549.3 | 3560.31 | 305.805418 | 306.754032 |
| 30 | MACHINE CENTER 4 | 3670.76 | 3872.528 | 316.270334 | 333.654535 |
| 31 | AS/RS CART | 3806.8 | 3817.81 | 327.974221 | 328.922836 |
| 32 | AS/RS CART | 3849.08 | 3860.09 | 331.634271 | 332.582885 |
| 33 | MACHINE CENTER 5 | 3911.17 | 4440.832 | 336.983905 | 382.619245 |
| 34 | AS/RS CART | 3922.2 | 3933.21 | 337.934243 | 338.882858 |
| 35 | MINI-MOVER-5 | 3928.47 | 4115.339 | 338.474462 | 354.623139 |
| 36 | AS/RS CART | 4414.21 | 4425.22 | 380.32551 | 381.274125 |
| 37 | MACHINE CENTER 1 | 4578.37 | 4857.72 | 394.46943 | 427.153934 |
| 38 | AS/RS CART | 4649.39 | 4660.4 | 400.588468 | 401.537083 |
| 39 | AS/RS CART | 4694.17 | 4705.18 | 404.448665 | 405.395299 |
| 40 | AS/RS CART | 4769.2 | 4780.21 | 410.911221 | 411.859836 |
| 41 | AS/RS CART | 4848.47 | 4859.48 | 417.741074 | 418.689688 |
| 42 | AS/RS CART | 4890.68 | 4901.69 | 421.37786 | 422.326475 |
| 43 | AS/RS CART | 5248.97 | 5259.98 | 452.247397 | 453.196012 |
| 44 | AS/RS CART | 5323.79 | 5334.8 | 458.694341 | 459.642955 |
| 45 | MACHINE CENTER 1 | 5349.29 | 5728.61 | 460.88892 | 493.573373 |
| 46 | AS/RS CART | 5385.14 | 5396.15 | 463.980218 | 464.928832 |
| 47 | MACHINE CENTER 2 | 5413.12 | 5780.946 | 466.390957 | 498.359422 |
| 48 | AS/RS CART | 5602.38 | 5613.39 | 482.887477 | 483.846032 |
| 49 | MINI-MOVER-5 | 5765.51 | 5952.338 | 496.752654 | 512.90133 |
| 50 | AS/RS CART | 5839.33 | 5850.34 | 503.112836 | 504.061352 |
| 51 | MACHINE CENTER 6 | 5850.19 | 6378.852 | 504.048628 | 549.663927 |
| 52 | AS/RS CART | 5954.63 | 5965.64 | 513.047112 | 513.995726 |
| 53 | MACHINE CENTER 3 | 5970.36 | 7160.058 | 514.402399 | 616.908017 |
| 54 | AS/RS CART | 6054.36 | 6065.37 | 521.633735 | 522.5884 |
| 55 | AS/RS CART | 6372.66 | 6383.67 | 549.064303 | 550.012924 |
| 56 | AS/RS CART | 6407.88 | 6418.89 | 552.098842 | 553.047457 |
| 57 | AS/RS CART | 6445.38 | 6456.39 | 555.329818 | 556.278433 |
| 58 | AS/RS CART | 6537.66 | 6548.67 | 563.290604 | 564.239213 |
| 59 | AS/RS CART | 6706.2 | 6717.21 | 577.801903 | 578.750517 |
| 60 | AS/RS CART | 6859.08 | 6870.09 | 590.973945 | 591.92256 |
| 61 | AS/RS CART | 6984.24 | 6995.25 | 601.757651 | 602.706265 |
| 62 | AS/RS CART | 7079.82 | 7090.83 | 609.992763 | 610.941377 |
| 63 | AS/RS CART | 7246.88 | 7257.89 | 624.369313 | 625.317928 |
| 64 | MINI-MOVER-5 | 7248.36 | 7435.763 | 624.514061 | 640.662736 |
| 65 | AS/RS CART | 7324.44 | 7335.45 | 631.069085 | 632.01769 |
| 66 | AS/RS CART | 7421.22 | 7432.23 | 639.407562 | 640.356133 |
| 67 | AS/RS CART | 7484.28 | 7495.29 | 644.840777 | 645.789392 |
| 68 | AS/RS CART | 7575 | 7586.01 | 652.657154 | 653.605769 |
| 69 | MINI-MOVER-5 | 7660.2 | 7847.623 | 659.997332 | 676.146623 |
| 70 | MACHINE CENTER 5 | 7686.12 | 8215.792 | 662.231193 | 707.869522 |
| 71 | AS/RS CART | 7744.68 | 7755.69 | 667.276675 | 668.225289 |
| 72 | AS/RS CART | 7847.34 | 7858.35 | 676.121795 | 677.070409 |
| 73 | AS/RS CART | 7891.56 | 7902.57 | 679.931762 | 680.880376 |
| 74 | AS/RS CART | 8048.16 | 8059.17 | 693.424318 | 694.372932 |
| 75 | AS/RS CART | 8340.66 | 8351.67 | 718.62593 | 719.574545 |

DECISION RULE SET= SLACK/RANDOM
TIME SCALING FACTOR= 11.6784 ; SIMULATION TIME= 719.276813

| NO. | FAILED COMPONENT | ACTUAL FAILING TIME | ACTUAL RECOVERY TIME | ADJUSTED FAILING TIME | ADJUSTED RECOVERY TIME |
|---|---|---|---|---|---|
| 1 | AS/RS CART | 75.744 | 86.754 | 6.48581998 | 7.42858811 |
| 2 | AS/RS CART | 151.29 | 162.3 | 12.9546856 | 13.8974517 |
| 3 | AS/RS CART | 188.91 | 199.92 | 16.1760173 | 17.1187834 |
| 4 | AS/RS CART | 387.06 | 398.07 | 33.1432389 | 34.0860049 |
| 5 | MINI-MOVER-5 | 567.338 | 754.784 | 48.5799425 | 64.6300538 |
| 6 | AS/RS CART | 810.636 | 821.646 | 69.4132759 | 70.3560413 |
| 7 | AS/RS CART | 931.674 | 942.684 | 79.777538 | 80.7203041 |
| 8 | AS/RS CART | 994.56 | 1005.57 | 85.162351 | 86.1051172 |
| 9 | MACHINE CENTER 4 | 1038.47 | 1240.238 | 88.9222339 | 106.199308 |
| 10 | AS/RS CART | 1133.95 | 1144.96 | 97.0980614 | 98.0408275 |
| 11 | AS/RS CART | 1255.38 | 1266.39 | 107.494177 | 108.436843 |
| 12 | AS/RS CART | 1292.76 | 1303.77 | 110.696871 | 111.639437 |
| 13 | AS/RS CART | 1344.59 | 1355.6 | 115.134779 | 116.077545 |
| 14 | AS/RS CART | 1386.1 | 1397.11 | 118.689204 | 119.63197 |
| 15 | AS/RS CART | 1551.55 | 1562.56 | 132.856384 | 133.799151 |
| 16 | AS/RS CART | 1720.57 | 1731.58 | 147.329257 | 148.272023 |
| 17 | AS/RS CART | 1822.37 | 1833.38 | 156.046205 | 156.988971 |
| 18 | AS/RS CART | 1914.59 | 1925.6 | 163.942835 | 164.885601 |
| 19 | AS/RS CART | 2005.98 | 2016.99 | 171.768393 | 172.711159 |
| 20 | AS/RS CART | 2111.21 | 2122.22 | 180.779045 | 181.721811 |
| 21 | AS/RS CART | 2283.37 | 2294.38 | 195.52079 | 196.463557 |
| 22 | AS/RS CART | 2561.25 | 2572.26 | 219.315146 | 220.257912 |
| 23 | AS/RS CART | 2689.37 | 2700.38 | 230.285827 | 231.228593 |
| 24 | MACHINE CENTER 2 | 2855.12 | 3202.948 | 244.478686 | 274.262393 |
| 25 | AS/RS CART | 2881.51 | 2892.52 | 246.738423 | 247.681189 |
| 26 | AS/RS CART | 3090.55 | 3101.56 | 264.638135 | 265.580902 |
| 27 | AS/RS CART | 3245.77 | 3256.78 | 277.929339 | 278.872106 |
| 28 | AS/RS CART | 3336.7 | 3347.71 | 285.715509 | 286.658275 |
| 29 | AS/RS CART | 3549.3 | 3560.31 | 303.920058 | 304.862824 |
| 30 | MACHINE CENTER 4 | 3670.76 | 3872.528 | 314.320455 | 331.597479 |
| 31 | AS/RS CART | 3806.6 | 3817.61 | 325.952185 | 326.894951 |
| 32 | AS/RS CART | 3849.06 | 3860.09 | 329.58567 | 330.532436 |
| 33 | MACHINE CENTER 5 | 3911.17 | 4440.832 | 334.908323 | 380.26031 |
| 34 | AS/RS CART | 3922.2 | 3933.21 | 335.850801 | 336.793563 |
| 35 | MINI-MOVER-5 | 3929.47 | 4115.988 | 336.38789 | 352.438006 |
| 36 | AS/RS CART | 4414.21 | 4425.22 | 377.980717 | 378.923483 |
| 37 | MACHINE CENTER 1 | 4578.37 | 4957.72 | 392.037437 | 424.520452 |
| 38 | AS/RS CART | 4649.39 | 4660.4 | 398.118743 | 399.061515 |
| 39 | AS/RS CART | 4694.17 | 4705.18 | 401.953179 | 402.895945 |
| 40 | AS/RS CART | 4769.2 | 4780.21 | 408.37786 | 409.320626 |
| 41 | AS/RS CART | 4848.47 | 4859.48 | 415.165605 | 416.108371 |
| 42 | AS/RS CART | 4890.69 | 4901.69 | 418.77987 | 419.722736 |
| 43 | AS/RS CART | 5248.97 | 5259.98 | 449.459636 | 450.402452 |
| 44 | AS/RS CART | 5323.79 | 5334.8 | 455.866388 | 456.809152 |
| 45 | MACHINE CENTER 1 | 5349.26 | 5728.61 | 458.047335 | 490.530381 |
| 46 | AS/RS CART | 5385.14 | 5396.15 | 461.119874 | 462.06244 |
| 47 | MACHINE CENTER 2 | 5413.12 | 5760.946 | 463.51555 | 493.299253 |
| 48 | AS/RS CART | 5602.38 | 5613.39 | 479.721537 | 480.664304 |
| 49 | MINI-MOVER-5 | 5765.51 | 5952.936 | 493.69006 | 509.739177 |
| 50 | AS/RS CART | 5839.33 | 5850.34 | 500.011131 | 500.953898 |
| 51 | MACHINE CENTER 6 | 5850.19 | 6379.252 | 500.941054 | 546.23584 |
| 52 | AS/RS CART | 5954.63 | 5965.64 | 509.88406 | 510.826829 |
| 53 | MACHINE CENTER 3 | 5970.36 | 7160.053 | 511.230981 | 613.102851 |
| 54 | AS/RS CART | 6054.36 | 6065.37 | 518.423757 | 519.366523 |
| 55 | AS/RS CART | 6372.66 | 6383.67 | 545.679203 | 546.621969 |
| 56 | AS/RS CART | 6407.88 | 6418.89 | 548.695027 | 549.637793 |
| 57 | AS/RS CART | 6445.38 | 6456.39 | 551.906033 | 552.848849 |
| 58 | AS/RS CART | 6537.56 | 6548.57 | [illegible] | [illegible] |
| 59 | AS/RS CART | [illegible] | 6717.31 | 574.233633 | [illegible] |

| | | | | | |
|---|---|---|---|---|---|
| 60 | AS/RS CART | 6659.26 | 6670.23 | [illegible] | [illegible] |
| 61 | AS/RS CART | 3334.24 | 3335.25 | [illegible] | [illegible] |
| 62 | AS/RS CART | 7079.82 | 7090.83 | 606.232018 | 607.174734 |
| 63 | AS/RS CART | 7246.88 | 7257.89 | 620.513934 | 621.4627 |
| 64 | MINI-MOVER-5 | 7249.36 | 7435.788 | 620.68379 | 638.712306 |
| 65 | AS/RS CART | 7324.44 | 7335.45 | 627.17833 | 628.121147 |
| 66 | AS/RS CART | 7421.22 | 7432.23 | 635.485475 | 636.408241 |
| 67 | AS/RS CART | 7484.28 | 7495.29 | 640.865187 | 641.807953 |
| 68 | AS/RS CART | 7575 | 7586.01 | 648.833374 | 649.57614 |
| 69 | MINI-MOVER-5 | 7580.2 | 7847.828 | 655.928894 | 671.378011 |
| 70 | MACHINE CENTER 5 | 7666.12 | 8215.782 | 658.148377 | 703.502363 |
| 71 | AS/RS CART | 7744.69 | 7755.69 | 663.162762 | 664.105528 |
| 72 | AS/RS CART | 7847.34 | 7858.35 | 671.85335 | 672.898118 |
| 73 | AS/RS CART | 7891.58 | 7902.57 | 675.739828 | 676.682534 |
| 74 | AS/RS CART | 8049.16 | 8059.17 | 689.149193 | 690.091964 |
| 75 | AS/RS CART | 8340.66 | 8351.67 | 714.195438 | 715.138204 |

DECISION RULE SET= SLACK/FMFS
TIME SCALING FACTOR= 11.7574 ; SIMULATION TIME= 714.44387

| NO. | FAILED COMPONENT | ACTUAL FAILING TIME | ACTUAL RECOVERY TIME | ADJUSTED FAILING TIME | ADJUSTED RECOVERY TIME |
|---|---|---|---|---|---|
| 1 | AS/RS CART | 75.744 | 86.754 | 6.44224063 | 7.37867216 |
| 2 | AS/RS CART | 151.29 | 162.3 | 12.8676406 | 13.8040723 |
| 3 | AS/RS CART | 188.91 | 199.92 | 16.0673278 | 17.0037593 |
| 4 | AS/RS CART | 387.06 | 398.07 | 32.9205437 | 33.8569752 |
| 5 | MINI-MOVER-5 | 567.336 | 754.764 | 48.2535255 | 64.194805 |
| 6 | AS/RS CART | 810.638 | 821.646 | 68.9468761 | 69.8833078 |
| 7 | AS/RS CART | 931.674 | 942.684 | 79.241489 | 80.1779305 |
| 9 | AS/RS CART | 994.56 | 1005.57 | 84.5901305 | 85.526582 |
| 9 | MACHINE CENTER 4 | 1038.47 | 1240.238 | 88.3247898 | 105.485737 |
| 10 | AS/RS CART | 1133.85 | 1144.86 | 96.4458427 | 97.3820743 |
| 11 | AS/RS CART | 1255.36 | 1266.37 | 106.771905 | 107.708337 |
| 12 | AS/RS CART | 1292.76 | 1303.77 | 109.952881 | 110.889312 |
| 13 | AS/RS CART | 1344.59 | 1355.6 | 114.381188 | 115.2876 |
| 14 | AS/RS CART | 1386.1 | 1397.11 | 117.891711 | 118.828142 |
| 15 | AS/RS CART | 1551.55 | 1562.56 | 131.9637 | 132.900131 |
| 16 | AS/RS CART | 1720.57 | 1731.58 | 146.339327 | 147.275758 |
| 17 | AS/RS CART | 1822.37 | 1833.38 | 154.997704 | 155.934135 |
| 18 | AS/RS CART | 1914.59 | 1925.6 | 162.841274 | 163.777708 |
| 19 | AS/RS CART | 2005.38 | 2016.39 | 170.614251 | 171.550683 |
| 20 | AS/RS CART | 2111.21 | 2122.22 | 179.564359 | 180.500791 |
| 21 | AS/RS CART | 2283.37 | 2294.38 | 194.207053 | 195.143484 |
| 22 | AS/RS CART | 2561.25 | 2572.26 | 217.84153 | 218.777961 |
| 23 | AS/RS CART | 2689.37 | 2700.38 | 228.738497 | 229.674923 |
| 24 | MACHINE CENTER 2 | 2855.12 | 3202.946 | 242.836201 | 272.419532 |
| 25 | AS/RS CART | 2881.51 | 2892.52 | 245.080545 | 246.016977 |
| 26 | AS/RS CART | 3090.55 | 3101.56 | 262.859986 | 263.796418 |
| 27 | AS/RS CART | 3245.77 | 3256.78 | 276.061884 | 276.998316 |
| 28 | AS/RS CART | 3336.7 | 3347.71 | 283.795737 | 284.732169 |
| 29 | AS/RS CART | 3549.3 | 3560.31 | 301.877966 | 302.814398 |
| 30 | MACHINE CENTER 4 | 3670.76 | 3872.523 | 312.208481 | 329.369418 |
| 31 | AS/RS CART | 3206.6 | 3817.81 | 323.762056 | 324.698436 |
| 32 | AS/RS CART | 3849.08 | 3860.09 | 327.3751 | 328.311532 |
| 33 | MACHINE CENTER 5 | 3911.17 | 4440.832 | 332.656029 | 377.705275 |
| 34 | AS/RS CART | 3922.2 | 3933.21 | 333.594162 | 334.530593 |
| 35 | MINI-MOVER-5 | 3822.47 | 4115.892 | 334.127443 | 350.066725 |
| 36 | AS/RS CART | 4414.21 | 4425.22 | 375.440999 | 376.37743 |
| 37 | MACHINE CENTER 1 | 4572.37 | 4957.72 | 388.403269 | 421.668056 |
| 38 | AS/RS CART | 4649.39 | 4660.4 | 395.44372 | 396.380152 |
| 39 | AS/RS CART | 4694.17 | 4705.18 | 399.252385 | 400.188817 |
| 40 | AS/RS CART | 4769.2 | 4780.21 | 405.633893 | 406.57033 |
| 41 | AS/RS CART | [illegible] | [illegible] | [illegible] | [illegible] |
| 42 | AS/RS CART | [illegible] | [illegible] | [illegible] | [illegible] |

| | | | | | |
|---|---|---|---|---|---|
| 43 | AS/RS CART | 5243.37 | 5254.38 | 446.439563 | 447.37312 |
| 44 | AS/RS CART | 5323.79 | 5334.8 | 452.303341 | 453.239772 |
| 45 | MACHINE CENTER 1 | 5349.26 | 5728.81 | 454.669636 | 487.234423 |
| 46 | AS/RS CART | 5385.14 | 5396.15 | 458.021331 | 458.957763 |
| 47 | MACHINE CENTER 2 | 5413.12 | 5780.946 | 460.401109 | 488.38469 |
| 48 | AS/RS CART | 5602.38 | 5613.39 | 476.498205 | 477.434637 |
| 49 | MINI-MOVER-5 | 5765.51 | 5952.938 | 490.372872 | 506.314151 |
| 50 | AS/RS CART | 5839.33 | 5850.34 | 496.65147 | 497.587902 |
| 51 | MACHINE CENTER 6 | 5850.19 | 6379.852 | 497.575144 | 542.62439 |
| 52 | AS/RS CART | 5954.83 | 5965.84 | 506.45806 | 507.394492 |
| 53 | MACHINE CENTER 3 | 5970.36 | 7180.059 | 507.795941 | 608.883109 |
| 54 | AS/RS CART | 6054.36 | 6065.37 | 514.940378 | 515.876803 |
| 55 | AS/RS CART | 6372.66 | 6383.67 | 542.01389 | 542.949121 |
| 56 | AS/RS CART | 6407.66 | 6418.83 | 545.00825 | 545.944632 |
| 57 | AS/RS CART | 6445.38 | 6456.39 | 548.197731 | 549.134163 |
| 58 | AS/RS CART | 6537.66 | 6548.67 | 556.046405 | 556.982837 |
| 59 | AS/RS CART | 6706.2 | 6717.21 | 570.381207 | 571.317638 |
| 60 | AS/RS CART | 6859.08 | 6870.09 | 583.384081 | 584.320513 |
| 61 | AS/RS CART | 6884.24 | 6895.25 | 584.029292 | 584.965724 |
| 62 | AS/RS CART | 7079.82 | 7090.83 | 602.158641 | 603.085072 |
| 63 | AS/RS CART | 7246.88 | 7257.89 | 616.350554 | 617.286985 |
| 64 | MINI-MOVER-5 | 7249.38 | 7435.798 | 616.493442 | 632.434722 |
| 65 | AS/RS CART | 7324.44 | 7335.45 | 622.964261 | 623.900692 |
| 66 | AS/RS CART | 7421.22 | 7432.23 | 631.195873 | 632.132104 |
| 67 | AS/RS CART | 7484.28 | 7495.29 | 636.559103 | 637.495534 |
| 68 | AS/RS CART | 7575 | 7586.01 | 644.275085 | 645.211526 |
| 69 | MINI-MOVER-5 | 7660.2 | 7847.628 | 651.521595 | 667.492375 |
| 70 | MACHINE CENTER 5 | 7695.12 | 8215.782 | 653.728164 | 698.77541 |
| 71 | AS/RS CART | 7744.68 | 7755.69 | 658.706857 | 659.643288 |
| 72 | AS/RS CART | 7847.34 | 7858.35 | 667.438379 | 668.374811 |
| 73 | AS/RS CART | 7891.58 | 7902.57 | 671.189415 | 672.135846 |
| 74 | AS/RS CART | 8048.16 | 8059.17 | 684.518686 | 685.455118 |
| 75 | AS/RS CART | 8340.66 | 8351.67 | 709.396635 | 710.333067 |

DECISION RULE SET= SLACK/NINQ
TIME SCALING FACTOR= 11.599 : SIMULATION TIME= 724.200362

| NO. | FAILED COMPONENT | ACTUAL FAILING TIME | ACTUAL RECOVERY TIME | ADJUSTED FAILING TIME | ADJUSTED RECOVERY TIME |
|---|---|---|---|---|---|
| 1 | AS/RS CART | 75.744 | 86.754 | 6.53021813 | 7.47343735 |
| 2 | AS/RS CART | 151.29 | 162.3 | 13.0433658 | 13.9925856 |
| 3 | AS/RS CART | 188.91 | 199.92 | 16.2867489 | 17.2358638 |
| 4 | AS/RS CART | 387.06 | 398.07 | 33.3701181 | 34.3193373 |
| 5 | MINI-MOVER-5 | 567.338 | 754.764 | 48.9124824 | 65.0714717 |
| 6 | AS/RS CART | 810.636 | 821.646 | 69.8884387 | 70.8375584 |
| 7 | AS/RS CART | 931.674 | 942.684 | 80.3236436 | 81.2728684 |
| 8 | AS/RS CART | 994.56 | 1005.57 | 85.7453229 | 86.6945426 |
| 9 | MACHINE CENTER 4 | 1026.47 | 1240.238 | 88.5305841 | 106.926287 |
| 10 | AS/RS CART | 1133.85 | 1144.86 | 97.7627382 | 98.711958 |
| 11 | AS/RS CART | 1255.36 | 1266.37 | 108.23002 | 109.17924 |
| 12 | AS/RS CART | 1292.76 | 1303.77 | 111.454436 | 112.403655 |
| 13 | AS/RS CART | 1344.59 | 1355.6 | 115.922924 | 116.872144 |
| 14 | AS/RS CART | 1386.1 | 1397.11 | 119.501681 | 120.450901 |
| 15 | AS/RS CART | 1551.55 | 1562.56 | 133.765542 | 134.715062 |
| 16 | AS/RS CART | 1720.57 | 1731.58 | 148.337788 | 149.287008 |
| 17 | AS/RS CART | 1822.37 | 1833.38 | 157.114406 | 158.063626 |
| 18 | AS/RS CART | 1914.59 | 1925.6 | 165.065092 | 166.014312 |
| 19 | AS/RS CART | 2005.99 | 2016.99 | 172.944216 | 173.893435 |
| 20 | AS/RS CART | 2111.21 | 2122.22 | 182.016553 | 182.965773 |
| 21 | AS/RS CART | 2283.37 | 2294.33 | 196.853212 | 197.803432 |
| 22 | AS/RS CART | 2561.25 | 2572.26 | 220.81645 | 221.76587 |
| 23 | AS/RS CART | 2689.37 | 2700.38 | 231.86223 | 232.811449 |
| 24 | MACHINE CENTER 2 | 2855.12 | 3202.946 | 246.152255 | 276.13384 |
| 25 | AS/RS CART | 2861.51 | [illegible] | 246.427451 | [illegible] |
| 26 | AS/RS CART | [illegible] | [illegible] | [illegible] | [illegible] |

| | | | | | |
|---|---|---|---|---|---|
| 27 | AS/RS CART | 3245.77 | 3256.73 | 279.631342 | 280.781122 |
| 28 | AS/RS CART | 3335.7 | 3347.71 | 287.671351 | 288.620371 |
| 29 | AS/RS CART | 3549.3 | 3560.31 | 306.000517 | 306.949737 |
| 30 | MACHINE CENTER 4 | 3670.76 | 3872.528 | 316.47211 | 333.867402 |
| 31 | AS/RS CART | 3806.8 | 3817.81 | 328.183464 | 329.132684 |
| 32 | AS/RS CART | 3849.08 | 3860.09 | 331.845849 | 332.795069 |
| 33 | MACHINE CENTER 5 | 3911.17 | 4440.832 | 337.198897 | 382.86335 |
| 34 | AS/RS CART | 3922.2 | 3933.21 | 338.14984 | 339.09906 |
| 35 | MINI-MOVER-5 | 3923.47 | 4115.898 | 338.890404 | 354.849383 |
| 36 | AS/RS CART | 4414.21 | 4425.22 | 380.568153 | 381.517372 |
| 37 | MACHINE CENTER 1 | 4578.37 | 4957.72 | 394.721097 | 427.428502 |
| 38 | AS/RS CART | 4649.39 | 4660.4 | 400.844038 | 401.793253 |
| 39 | AS/RS CART | 4694.17 | 4705.18 | 404.704718 | 405.653936 |
| 40 | AS/RS CART | 4769.2 | 4780.21 | 411.173377 | 412.122597 |
| 41 | AS/RS CART | 4848.47 | 4859.48 | 418.007587 | 418.956807 |
| 42 | AS/RS CART | 4890.68 | 4901.69 | 421.646694 | 422.595914 |
| 43 | AS/RS CART | 5248.97 | 5259.98 | 452.536426 | 453.485645 |
| 44 | AS/RS CART | 5323.79 | 5334.8 | 458.986982 | 459.936201 |
| 45 | MACHINE CENTER 1 | 5349.26 | 5728.61 | 461.182861 | 493.888266 |
| 46 | AS/RS CART | 5385.14 | 5396.15 | 464.276231 | 465.225451 |
| 47 | MACHINE CENTER 2 | 5413.12 | 5780.946 | 466.688502 | 498.676093 |
| 48 | AS/RS CART | 5602.38 | 5613.39 | 483.005432 | 483.954653 |
| 49 | MINI-MOVER-5 | 5765.51 | 5952.938 | 497.069575 | 513.228555 |
| 50 | AS/RS CART | 5839.33 | 5850.34 | 503.433917 | 504.383137 |
| 51 | MACHINE CENTER 6 | 5850.19 | 6379.852 | 504.370204 | 550.034853 |
| 52 | AS/RS CART | 5954.63 | 5965.64 | 513.374429 | 514.323649 |
| 53 | MACHINE CENTER 3 | 5970.38 | 7180.056 | 514.73058 | 617.299595 |
| 54 | AS/RS CART | 6054.36 | 6065.37 | 521.972584 | 522.921804 |
| 55 | AS/RS CART | 6372.66 | 6383.67 | 549.414605 | 550.363825 |
| 56 | AS/RS CART | 6407.68 | 6418.69 | 552.451073 | 553.400294 |
| 57 | AS/RS CART | 6445.38 | 6456.39 | 555.684111 | 556.633331 |
| 58 | AS/RS CART | 6537.66 | 6548.67 | 563.638969 | 564.588189 |
| 59 | AS/RS CART | 6706.2 | 6717.21 | 578.170532 | 579.119752 |
| 60 | AS/RS CART | 6858.68 | 6870.09 | 591.350978 | 592.300198 |
| 61 | AS/RS CART | 6984.24 | 6995.25 | 602.141564 | 603.090784 |
| 62 | AS/RS CART | 7079.22 | 7090.23 | 610.38193 | 611.331149 |
| 63 | AS/RS CART | 7246.68 | 7257.69 | 624.767652 | 625.716872 |
| 64 | MINI-MOVER-5 | 7248.36 | 7435.788 | 624.912492 | 641.071472 |
| 65 | AS/RS CART | 7324.44 | 7335.45 | 631.471679 | 632.420898 |
| 66 | AS/RS CART | 7421.22 | 7432.23 | 639.815502 | 640.764721 |
| 67 | AS/RS CART | 7484.28 | 7495.29 | 645.252177 | 646.201397 |
| 68 | AS/RS CART | 7575 | 7586.01 | 653.073541 | 654.022761 |
| 69 | MINI-MOVER-5 | 7660.2 | 7847.628 | 660.419002 | 676.577981 |
| 70 | MACHINE CENTER 5 | 7696.12 | 8215.782 | 662.853877 | 708.318131 |
| 71 | AS/RS CART | 7744.68 | 7755.69 | 667.702388 | 668.651608 |
| 72 | AS/RS CART | 7847.34 | 7858.35 | 676.553151 | 677.502371 |
| 73 | AS/RS CART | 7891.56 | 7902.57 | 680.365543 | 681.314763 |
| 74 | AS/RS CART | 8048.16 | 8059.17 | 693.868713 | 694.815933 |
| 75 | AS/RS CART | 8340.56 | 8351.67 | 719.084404 | 720.033624 |

DECISION RULE SET= SLACK/WINQ
TIME SCALING FACTOR= 11.6528 ; SIMULATION TIME= 728.35373

| NO. | FAILED COMPONENT | ACTUAL FAILING TIME | ACTUAL RECOVERY TIME | ADJUSTED FAILING TIME | ADJUSTED RECOVERY TIME |
|---|---|---|---|---|---|
| 1 | AS/RS CART | 75.744 | 86.754 | 6.50026865 | 7.44490595 |
| 2 | AS/RS CART | 151.29 | 152.3 | 12.9831457 | 13.927363 |
| 3 | AS/RS CART | 198.91 | 199.92 | 16.2115543 | 17.1563916 |
| 4 | AS/RS CART | 387.06 | 398.07 | 33.2160511 | 34.1603864 |
| 5 | MINI-MOVER-5 | 567.336 | 754.764 | 48.6366679 | 64.7710422 |
| 6 | AS/RS CART | 810.636 | 821.646 | 69.5657697 | 70.5106263 |
| 7 | AS/RS CART | 931.674 | 942.684 | 79.9528011 | 80.8973563 |
| 8 | AS/RS CART | 994.56 | 1005.57 | 85.3494439 | 86.2942313 |
| 9 | MACHINE CENTER 4 | 1039.47 | 1342.338 | 89.11767 [illegible] | 126.4 [illegible] |
| 10 | AS/RS CART | 1133.95 | 1144.95 | 97.3 [illegible] | 98.2 [illegible] |

| | | | | | |
|---|---|---|---|---|---|
| 11 | AS/RS CART | 1255.36 | 1258.37 | 107.730331 | 108.675136 |
| 12 | AS/RS CART | 1292.75 | 1303.77 | 110.33336 | 111.384357 |
| 13 | AS/RS CART | 1344.59 | 1355.6 | 115.387718 | 116.332555 |
| 14 | AS/RS CART | 1336.1 | 1397.11 | 119.949952 | 119.894789 |
| 15 | AS/RS CART | 1551.55 | 1562.56 | 133.148256 | 134.093094 |
| 16 | AS/RS CART | 1720.57 | 1731.58 | 147.652925 | 148.597762 |
| 17 | AS/RS CART | 1822.37 | 1833.38 | 156.389022 | 157.33386 |
| 18 | AS/RS CART | 1914.59 | 1925.6 | 164.303 | 165.247833 |
| 19 | AS/RS CART | 2005.98 | 2016.99 | 172.14575 | 173.080538 |
| 20 | AS/RS CART | 2111.21 | 2122.22 | 181.176198 | 182.121035 |
| 21 | AS/RS CART | 2283.37 | 2294.38 | 195.95033 | 196.895167 |
| 22 | AS/RS CART | 2561.25 | 2572.26 | 219.796959 | 220.741796 |
| 23 | AS/RS CART | 2689.37 | 2700.38 | 230.791741 | 231.736579 |
| 24 | MACHINE CENTER 2 | 2855.12 | 3202.946 | 245.01579 | 274.864325 |
| 25 | AS/RS CART | 2881.51 | 2892.52 | 247.280482 | 248.225319 |
| 26 | AS/RS CART | 3090.55 | 3101.56 | 265.219518 | 266.164355 |
| 27 | AS/RS CART | 3245.77 | 3256.78 | 278.539922 | 279.484753 |
| 28 | AS/RS CART | 3336.7 | 3347.71 | 286.343197 | 287.288034 |
| 29 | AS/RS CART | 3549.3 | 3560.31 | 304.587739 | 305.532576 |
| 30 | MACHINE CENTER 4 | 3670.76 | 3872.526 | 315.010884 | 332.325365 |
| 31 | AS/RS CART | 3806.6 | 3817.61 | 326.668269 | 327.613106 |
| 32 | AS/RS CART | 3849.08 | 3860.09 | 330.313745 | 331.258582 |
| 33 | MACHINE CENTER 5 | 3911.17 | 4440.832 | 335.642073 | 381.095703 |
| 34 | AS/RS CART | 3922.2 | 3933.21 | 336.588831 | 337.533463 |
| 35 | MINI-MOVER-5 | 3928.47 | 4115.898 | 337.126693 | 353.211074 |
| 36 | AS/RS CART | 4414.21 | 4425.22 | 378.811101 | 379.755939 |
| 37 | MACHINE CENTER 1 | 4579.37 | 4957.72 | 392.986703 | 425.45311 |
| 38 | AS/RS CART | 4649.39 | 4660.4 | 398.993375 | 399.938212 |
| 39 | AS/RS CART | 4694.17 | 4705.18 | 402.838228 | 403.781065 |
| 40 | AS/RS CART | 4769.2 | 4780.21 | 409.275024 | 410.219832 |
| 41 | AS/RS CART | 4848.47 | 4859.48 | 416.077681 | 417.022518 |
| 42 | AS/RS CART | 4890.68 | 4901.69 | 419.698986 | 420.644824 |
| 43 | AS/RS CART | 5248.97 | 5259.98 | 450.447103 | 451.39194 |
| 44 | AS/RS CART | 5323.79 | 5334.8 | 456.967977 | 457.812715 |
| 45 | MACHINE CENTER 1 | 5349.26 | 5723.61 | 459.053518 | 491.608026 |
| 46 | AS/RS CART | 5385.14 | 5396.15 | 462.132708 | 463.077544 |
| 47 | MACHINE CENTER 2 | 5413.12 | 5760.946 | 464.533846 | 494.382981 |
| 48 | AS/RS CART | 5602.38 | 5613.39 | 480.775436 | 481.720274 |
| 49 | MINI-MOVER-5 | 5765.51 | 5952.938 | 494.774847 | 510.859021 |
| 50 | AS/RS CART | 5839.33 | 5850.34 | 501.109605 | 502.054442 |
| 51 | MACHINE CENTER 6 | 5850.18 | 6379.852 | 502.041583 | 547.495194 |
| 52 | AS/RS CART | 5954.63 | 5965.64 | 511.004223 | 511.94326 |
| 53 | MACHINE CENTER 3 | 5970.36 | 7160.058 | 512.354113 | 614.448574 |
| 54 | AS/RS CART | 6054.36 | 6065.37 | 519.56293 | 520.507518 |
| 55 | AS/RS CART | 6372.66 | 6383.67 | 546.878004 | 547.822841 |
| 56 | AS/RS CART | 6407.88 | 6418.89 | 549.890453 | 550.845291 |
| 57 | AS/RS CART | 6445.38 | 6456.39 | 553.118564 | 554.063401 |
| 58 | AS/RS CART | 6537.66 | 6548.67 | 561.037891 | 561.982529 |
| 59 | AS/RS CART | 6706.2 | 6717.21 | 575.501167 | 576.446005 |
| 60 | AS/RS CART | 6859.08 | 6870.09 | 588.620761 | 589.565599 |
| 61 | AS/RS CART | 6984.24 | 6995.25 | 599.361527 | 600.306364 |
| 62 | AS/RS CART | 7079.82 | 7090.83 | 607.563548 | 608.508385 |
| 63 | AS/RS CART | 7246.68 | 7257.69 | 621.883153 | 622.82799 |
| 64 | MINI-MOVER-5 | 7248.36 | 7435.788 | 622.027324 | 638.111699 |
| 65 | AS/RS CART | 7324.44 | 7335.45 | 628.556227 | 629.501264 |
| 66 | AS/RS CART | 7421.22 | 7432.23 | 636.861527 | 637.806364 |
| 67 | AS/RS CART | 7484.28 | 7495.29 | 642.273102 | 643.217939 |
| 68 | AS/RS CART | 7575 | 7586.01 | 650.058355 | 651.003193 |
| 69 | MINI-MOVER-5 | 7660.2 | 7847.628 | 657.369903 | 673.454279 |
| 70 | MACHINE CENTER 5 | 7683.12 | 8215.782 | 659.334261 | 705.047386 |
| 71 | AS/RS CART | 7744.82 | 7755.83 | 664.613262 | 665.5645 |
| 72 | AS/RS CART | 7847.34 | 7858.35 | 673.423562 | 674.374399 |
| 73 | AS/RS CART | 7891.56 | 7902.57 | 677.224359 | 678.169196 |
| 74 | AS/RS CART | 8043.16 | 8053.17 | 690.663193 | 691.603029 |
| 75 | AS/RS CART | 8340.66 | 8351.67 | 715.764452 | 716.709289 |

DECISION RULE SET= 3/PT/RANDOM
TIME SCALING FACTOR= 11.7927 ; SIMULATION TIME= 712.30507

| NO. | FAILED COMPONENT | ACTUAL FAILING TIME | ACTUAL RECOVERY TIME | ADJUSTED FAILING TIME | ADJUSTED RECOVERY TIME |
|---|---|---|---|---|---|
| 1 | AS/RS CART | 75.744 | 86.754 | 6.42295858 | 7.35658501 |
| 2 | AS/RS CART | 151.29 | 162.3 | 12.8291231 | 13.7627515 |
| 3 | AS/RS CART | 188.91 | 199.92 | 16.0192322 | 16.9528607 |
| 4 | AS/RS CART | 387.06 | 398.07 | 32.8220001 | 33.7556285 |
| 5 | MINI-MOVER-5 | 567.336 | 754.764 | 48.1090845 | 64.0026457 |
| 6 | AS/RS CART | 810.836 | 821.846 | 68.7404921 | 69.6741205 |
| 7 | AS/RS CART | 931.674 | 942.684 | 79.0042993 | 79.9379277 |
| 8 | AS/RS CART | 994.56 | 1005.57 | 84.3368203 | 85.2704488 |
| 9 | MACHINE CENTER 4 | 1038.47 | 1240.238 | 88.0604103 | 105.169378 |
| 10 | AS/RS CART | 1133.95 | 1144.96 | 96.1569448 | 97.090573 |
| 11 | AS/RS CART | 1255.36 | 1266.37 | 106.452297 | 107.385925 |
| 12 | AS/RS CART | 1292.76 | 1303.77 | 109.62375 | 110.557370 |
| 13 | AS/RS CART | 1344.59 | 1355.6 | 114.018842 | 114.952471 |
| 14 | AS/RS CART | 1386.1 | 1397.11 | 117.538816 | 118.472445 |
| 15 | AS/RS CART | 1551.55 | 1562.56 | 131.568682 | 132.502311 |
| 16 | AS/RS CART | 1720.57 | 1731.58 | 145.901278 | 146.834306 |
| 17 | AS/RS CART | 1822.37 | 1833.38 | 154.533737 | 155.467365 |
| 18 | AS/RS CART | 1914.59 | 1925.6 | 162.353828 | 163.287456 |
| 19 | AS/RS CART | 2005.98 | 2016.99 | 170.103539 | 171.037167 |
| 20 | AS/RS CART | 2111.21 | 2122.22 | 179.026856 | 179.960484 |
| 21 | AS/RS CART | 2283.37 | 2294.38 | 193.625718 | 194.559346 |
| 22 | AS/RS CART | 2561.25 | 2572.26 | 217.189448 | 218.123076 |
| 23 | AS/RS CART | 2689.37 | 2700.38 | 228.053788 | 228.987425 |
| 24 | MACHINE CENTER 2 | 2855.12 | 3202.946 | 242.108101 | 271.604126 |
| 25 | AS/RS CART | 2881.51 | 2892.52 | 244.346927 | 245.280555 |
| 26 | AS/RS CART | 3090.55 | 3101.56 | 262.073147 | 263.006775 |
| 27 | AS/RS CART | 3245.77 | 3256.78 | 275.235527 | 276.169156 |
| 28 | AS/RS CART | 3336.7 | 3347.71 | 282.94623 | 283.879858 |
| 29 | AS/RS CART | 3549.3 | 3560.31 | 300.974332 | 301.90796 |
| 30 | MACHINE CENTER 4 | 3670.76 | 3872.528 | 311.273824 | 328.383482 |
| 31 | AS/RS CART | 3806.6 | 3817.61 | 322.792914 | 323.726543 |
| 32 | AS/RS CART | 3849.08 | 3860.09 | 326.395143 | 327.328771 |
| 33 | MACHINE CENTER 5 | 3911.17 | 4440.932 | 331.660264 | 376.574681 |
| 34 | AS/RS CART | 3922.2 | 3933.21 | 332.595589 | 333.528217 |
| 35 | MINI-MOVER-5 | 3928.47 | 4115.398 | 333.127274 | 349.020835 |
| 36 | AS/RS CART | 4414.21 | 4425.22 | 374.317163 | 375.250791 |
| 37 | MACHINE CENTER 1 | 4578.37 | 4957.72 | 388.237639 | 420.405244 |
| 38 | AS/RS CART | 4649.39 | 4660.4 | 394.260006 | 395.193637 |
| 39 | AS/RS CART | 4694.17 | 4705.18 | 398.057273 | 398.990901 |
| 40 | AS/RS CART | 4769.2 | 4780.21 | 404.419634 | 405.353312 |
| 41 | AS/RS CART | 4848.47 | 4859.48 | 411.141638 | 412.075267 |
| 42 | AS/RS CART | 4890.66 | 4901.69 | 414.720972 | 415.6546 |
| 43 | AS/RS CART | 5248.97 | 5259.98 | 445.103327 | 446.036955 |
| 44 | AS/RS CART | 5323.79 | 5334.8 | 451.44793 | 452.381556 |
| 45 | MACHINE CENTER 1 | 5349.26 | 5728.61 | 453.60774 | 485.775345 |
| 46 | AS/RS CART | 5385.14 | 5396.15 | 456.650301 | 457.583929 |
| 47 | MACHINE CENTER 2 | 5413.12 | 5760.946 | 459.022955 | 488.517591 |
| 48 | AS/RS CART | 5602.38 | 5613.39 | 475.071667 | 476.005295 |
| 49 | MINI-MOVER-5 | 5765.51 | 5952.935 | 488.905031 | 504.798562 |
| 50 | AS/RS CART | 5839.33 | 5850.34 | 495.164805 | 496.098434 |
| 51 | MACHINE CENTER 6 | 5850.19 | 6379.352 | 496.085714 | 541.20011 |
| 52 | AS/RS CART | 5954.63 | 5965.64 | 504.94204 | 505.875669 |
| 53 | MACHINE CENTER 3 | 5970.36 | 7160.259 | 506.275817 | 607.180132 |
| 54 | AS/RS CART | 6054.36 | 6065.37 | 513.398987 | 514.33[illegible] |
| 55 | AS/RS CART | 6372.66 | 6383.67 | 540.390241 | 541.32387 |
| 56 | AS/RS CART | 6407.38 | 6418.39 | 543.3[illegible] | 544.3[illegible] |
| 57 | AS/RS CART | 6445.32 | 6456.33 | 546.555733 | 547.4[illegible] |
| 58 | AS/RS CART | [illegible].96 | [illegible].97 | [illegible] | [illegible] |
| 59 | AS/RS CART | [illegible].2 | [illegible] | [illegible] | [illegible] |

| | | | | | |
|---|---|---|---|---|---|
| [illegible] | AS/RS CART | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | AS/RS CART | [illegible] | [illegible] | [illegible] | [illegible] |
| 62 | AS/RS CART | 7079.32 | 7090.33 | 600.359153 | 601.289731 |
| 63 | AS/RS CART | 7246.68 | 7257.69 | 614.505584 | 615.433213 |
| 64 | MINI-MOVER-5 | 7248.36 | 7435.738 | 614.648045 | 630.541806 |
| 65 | AS/RS CART | 7324.44 | 7335.45 | 621.099494 | 622.033122 |
| 66 | AS/RS CART | 7421.22 | 7432.23 | 629.306266 | 630.239895 |
| 67 | AS/RS CART | 7484.28 | 7495.29 | 634.653642 | 635.58727 |
| 68 | AS/RS CART | 7575 | 7586.01 | 642.348536 | 643.280165 |
| 69 | MINI-MOVER-5 | 7660.2 | 7847.828 | 649.571345 | 665.464906 |
| 70 | MACHINE CENTER 5 | 7686.12 | 8215.782 | 651.769315 | 696.683711 |
| 71 | AS/RS CART | 7744.68 | 7755.69 | 656.735099 | 657.668727 |
| 72 | AS/RS CART | 7847.34 | 7858.35 | 665.440484 | 666.374113 |
| 73 | AS/RS CART | 7891.56 | 7902.57 | 669.130182 | 670.12383 |
| 74 | AS/RS CART | 8048.16 | 8059.17 | 682.469683 | 683.403292 |
| 75 | AS/RS CART | 8340.66 | 8351.67 | 707.273143 | 708.206772 |

DECISION RULE SET= S/PT/FMFS
TIME SCALING FACTOR= 11.9217 ; SIMULATION TIME= 704.537493

| NO. | FAILED COMPONENT | ACTUAL FAILING TIME | ACTUAL RECOVERY TIME | ADJUSTED FAILING TIME | ADJUSTED RECOVERY TIME |
|---|---|---|---|---|---|
| 1 | AS/RS CART | 75.744 | 86.754 | 6.35345631 | 7.2768823 |
| 2 | AS/RS CART | 151.29 | 162.3 | 12.6903042 | 13.6138303 |
| 3 | AS/RS CART | 188.91 | 199.92 | 15.8458845 | 16.7694205 |
| 4 | AS/RS CART | 387.06 | 398.07 | 32.4668462 | 33.3903722 |
| 5 | MINI-MOVER-5 | 567.336 | 754.764 | 47.5885151 | 63.3100984 |
| 6 | AS/RS CART | 810.636 | 821.646 | 67.9966783 | 68.9202043 |
| 7 | AS/RS CART | 931.674 | 942.684 | 78.149425 | 79.072951 |
| 8 | AS/RS CART | 994.56 | 1005.57 | 83.4243438 | 84.3478688 |
| 9 | MACHINE CENTER 4 | 1038.47 | 1240.238 | 87.1075434 | 104.031975 |
| 10 | AS/RS CART | 1133.85 | 1144.86 | 95.1164683 | 96.0399943 |
| 11 | AS/RS CART | 1255.36 | 1266.37 | 105.300419 | 106.223945 |
| 12 | AS/RS CART | 1292.76 | 1303.77 | 108.437555 | 109.361081 |
| 13 | AS/RS CART | 1344.59 | 1355.6 | 112.785089 | 113.708615 |
| 14 | AS/RS CART | 1386.1 | 1397.11 | 116.266975 | 117.190501 |
| 15 | AS/RS CART | 1551.55 | 1562.56 | 130.14503 | 131.068559 |
| 16 | AS/RS CART | 1720.57 | 1731.58 | 144.322538 | 145.246064 |
| 17 | AS/RS CART | 1822.37 | 1833.38 | 152.861589 | 153.785114 |
| 18 | AS/RS CART | 1914.59 | 1925.6 | 160.597063 | 161.520589 |
| 19 | AS/RS CART | 2005.98 | 2016.99 | 168.262916 | 169.186442 |
| 20 | AS/RS CART | 2111.21 | 2122.22 | 177.089677 | 178.013203 |
| 21 | AS/RS CART | 2283.37 | 2294.38 | 191.53057 | 192.454096 |
| 22 | AS/RS CART | 2561.25 | 2572.26 | 214.839327 | 215.762853 |
| 23 | AS/RS CART | 2689.37 | 2700.38 | 225.586116 | 226.509642 |
| 24 | MACHINE CENTER 2 | 2855.12 | 3202.846 | 239.489334 | 268.665207 |
| 25 | AS/RS CART | 2881.51 | 2892.52 | 241.702945 | 242.626471 |
| 26 | AS/RS CART | 3090.55 | 3101.56 | 259.237357 | 260.160883 |
| 27 | AS/RS CART | 3245.77 | 3256.78 | 272.257312 | 273.180838 |
| 28 | AS/RS CART | 3336.7 | 3347.71 | 279.88458 | 280.808106 |
| 29 | AS/RS CART | 3549.3 | 3560.31 | 297.717607 | 298.641133 |
| 30 | MACHINE CENTER 4 | 3670.76 | 3872.528 | 307.905752 | 324.830184 |
| 31 | AS/RS CART | 3806.6 | 3817.61 | 319.3001 | 320.223626 |
| 32 | AS/RS CART | 3849.08 | 3860.09 | 322.86335 | 323.786876 |
| 33 | MACHINE CENTER 5 | 3911.17 | 4440.832 | 328.0715 | 372.499895 |
| 34 | AS/RS CART | 3922.2 | 3933.21 | 328.996704 | 329.92023 |
| 35 | MINI-MOVER-5 | 3928.47 | 4115.892 | 329.522635 | 345.244213 |
| 36 | AS/RS CART | 4414.21 | 4425.22 | 370.266824 | 371.19035 |
| 37 | MACHINE CENTER 1 | 4578.37 | 4957.72 | 384.038673 | 415.858733 |
| 38 | AS/RS CART | 4649.39 | 4660.4 | 389.993677 | 390.917403 |
| 39 | AS/RS CART | 4694.17 | 4705.18 | 393.750053 | 394.673578 |
| 40 | AS/RS CART | 4769.2 | 4780.21 | 400.043618 | 400.967144 |
| 41 | AS/RS CART | 4848.47 | 4859.48 | [illegible] | [illegible] |
| 42 | AS/RS CART | [illegible] | [illegible] | [illegible] | [illegible] |

| | | | | | |
|---|---|---|---|---|---|
| 43 | AS/RS CART | 5248.97 | 5259.98 | 440.23704 | 441.210528 |
| 44 | AS/RS CART | 5323.79 | 5334.8 | 446.56298 | 447.468519 |
| 45 | MACHINE CENTER 1 | 5349.86 | 5728.61 | 448.69943 | 480.519557 |
| 46 | AS/RS CART | 5385.14 | 5396.15 | 451.709063 | 452.632594 |
| 47 | MACHINE CENTER 2 | 5413.12 | 5790.946 | 454.056049 | 483.231922 |
| 48 | AS/RS CART | 5602.38 | 5613.39 | 469.931302 | 470.854823 |
| 49 | MINI-MOVER-5 | 5765.51 | 5952.939 | 483.614753 | 493.336337 |
| 50 | AS/RS CART | 5839.33 | 5850.34 | 489.808823 | 490.730349 |
| 51 | MACHINE CENTER 6 | 5850.19 | 6379.652 | 490.717767 | 535.146162 |
| 52 | AS/RS CART | 5954.63 | 5965.64 | 499.478283 | 500.401738 |
| 53 | MACHINE CENTER 3 | 5970.38 | 7160.058 | 500.797705 | 600.590352 |
| 54 | AS/RS CART | 6054.36 | 6065.37 | 507.84368 | 508.767206 |
| 55 | AS/RS CART | 6372.66 | 6383.67 | 534.542692 | 535.466418 |
| 56 | AS/RS CART | 6407.66 | 6418.69 | 537.487169 | 538.420685 |
| 57 | AS/RS CART | 6445.38 | 6456.39 | 540.642694 | 541.56622 |
| 58 | AS/RS CART | 6537.66 | 6548.67 | 548.3832 | 549.306727 |
| 59 | AS/RS CART | 6706.2 | 6717.21 | 562.520446 | 563.443972 |
| 60 | AS/RS CART | 6859.08 | 6870.09 | 575.34412 | 576.267347 |
| 61 | AS/RS CART | 6984.24 | 6995.25 | 585.842923 | 586.766149 |
| 62 | AS/RS CART | 7079.82 | 7090.83 | 593.859936 | 594.783463 |
| 63 | AS/RS CART | 7246.69 | 7257.69 | 607.856262 | 608.779788 |
| 64 | MINI-MOVER-5 | 7247.36 | 7435.788 | 607.997182 | 623.718785 |
| 65 | AS/RS CART | 7324.44 | 7335.45 | 614.378822 | 615.302348 |
| 66 | AS/RS CART | 7421.22 | 7432.23 | 622.496792 | 623.420318 |
| 67 | AS/RS CART | 7484.28 | 7495.29 | 627.786305 | 628.709831 |
| 68 | AS/RS CART | 7575 | 7586.01 | 635.395958 | 636.318485 |
| 69 | MINI-MOVER-5 | 7660.2 | 7847.626 | 642.54259 | 658.284174 |
| 70 | MACHINE CENTER 5 | 7686.12 | 8215.782 | 644.718777 | 689.145173 |
| 71 | AS/RS CART | 7744.68 | 7755.69 | 649.628828 | 650.552354 |
| 72 | AS/RS CART | 7847.34 | 7858.35 | 658.240016 | 659.163542 |
| 73 | AS/RS CART | 7891.56 | 7902.57 | 661.949219 | 662.872745 |
| 74 | AS/RS CART | 8046.16 | 8059.17 | 675.084929 | 676.008455 |
| 75 | AS/RS CART | 8340.86 | 8351.87 | 699.620021 | 700.543547 |

DECISION RULE SET= 3/PT/NINQ
TIME SCALING FACTOR= 11.6739 ; SIMULATION TIME= 719.553877

| NO. | FAILED COMPONENT | ACTUAL FAILING TIME | ACTUAL RECOVERY TIME | ADJUSTED FAILING TIME | ADJUSTED RECOVERY TIME |
|---|---|---|---|---|---|
| 1 | AS/RS CART | 75.744 | 86.754 | 6.4883201 | 7.43144365 |
| 2 | AS/RS CART | 151.28 | 162.3 | 12.9590793 | 13.9028038 |
| 3 | AS/RS CART | 188.91 | 199.92 | 16.1822527 | 17.1253823 |
| 4 | AS/RS CART | 387.06 | 398.07 | 33.1560147 | 34.0991443 |
| 5 | MINI-MOVER-5 | 567.336 | 754.764 | 48.5988688 | 64.6533717 |
| 6 | AS/RS CART | 810.636 | 821.646 | 69.4400329 | 70.3831625 |
| 7 | AS/RS CART | 931.674 | 942.684 | 79.8082503 | 80.7514196 |
| 8 | AS/RS CART | 994.56 | 1005.57 | 85.195179 | 86.1383036 |
| 9 | MACHINE CENTER 4 | 1032.47 | 1240.238 | 88.3565613 | 106.240245 |
| 10 | AS/RS CART | 1133.85 | 1144.86 | 97.1354303 | 98.0786138 |
| 11 | AS/RS CART | 1255.36 | 1266.37 | 107.535614 | 108.478743 |
| 12 | AS/RS CART | 1292.76 | 1303.77 | 110.739342 | 111.682471 |
| 13 | AS/RS CART | 1344.59 | 1355.6 | 115.17918 | 116.12229 |
| 14 | AS/RS CART | 1386.1 | 1397.11 | 118.734956 | 119.678085 |
| 15 | AS/RS CART | 1551.55 | 1562.56 | 132.907597 | 133.850727 |
| 16 | AS/RS CART | 1720.57 | 1731.58 | 147.386049 | 148.329175 |
| 17 | AS/RS CART | 1822.37 | 1833.38 | 156.106357 | 157.049485 |
| 18 | AS/RS CART | 1914.58 | 1925.6 | 164.006231 | 164.94916 |
| 19 | AS/RS CART | 2005.98 | 2016.99 | 171.834605 | 172.777735 |
| 20 | AS/RS CART | 2111.21 | 2122.22 | 180.848731 | 181.791351 |
| 21 | AS/RS CART | 2283.37 | 2294.38 | 195.596159 | 196.539285 |
| 22 | AS/RS CART | 2561.25 | 2572.26 | 219.399696 | 220.342816 |
| 23 | AS/RS CART | 2689.37 | 2700.38 | 230.374596 | 231.317739 |
| 24 | MACHINE CENTER 2 | 2855.12 | 3202.346 | 244.572936 | 274.36912 |
| 25 | AS/RS CART | 2931.51 | 2942.52 | [illegible] | 247.77[illegible] |
| 26 | AS/RS CART | 3090.55 | 3101.56 | [illegible] | [illegible] |

| | | | | | |
|---|---|---|---|---|---|
| 27 | AS/RS CART | 3245.77 | 3256.73 | 273.036475 | 273.973624 |
| 28 | AS/RS CART | 3335.7 | 3347.71 | 285.225645 | 286.168775 |
| 29 | AS/RS CART | 3549.3 | 3560.31 | 304.037811 | 304.980341 |
| 30 | MACHINE CENTER 4 | 3670.78 | 3872.528 | 314.441618 | 331.725302 |
| 31 | AS/RS CART | 3806.8 | 3817.81 | 326.077832 | 327.020861 |
| 32 | AS/RS CART | 3849.08 | 3860.09 | 329.718719 | 330.659843 |
| 33 | MACHINE CENTER 5 | 3911.17 | 4440.832 | 335.035421 | 380.408891 |
| 34 | AS/RS CART | 3922.2 | 3933.21 | 335.980284 | 336.923393 |
| 35 | MINI-MOVER-5 | 3928.47 | 4115.898 | 336.517359 | 352.572862 |
| 36 | AS/RS CART | 4414.21 | 4425.22 | 378.126419 | 379.069548 |
| 37 | MACHINE CENTER 1 | 4578.37 | 4957.72 | 392.188557 | 424.684125 |
| 38 | AS/RS CART | 4649.39 | 4660.4 | 398.272214 | 399.215344 |
| 39 | AS/RS CART | 4694.17 | 4705.18 | 402.108122 | 403.051251 |
| 40 | AS/RS CART | 4769.2 | 4780.21 | 408.53529 | 409.478403 |
| 41 | AS/RS CART | 4848.47 | 4859.48 | 415.325641 | 416.26877 |
| 42 | AS/RS CART | 4890.68 | 4901.69 | 418.941398 | 419.884529 |
| 43 | AS/RS CART | 5248.97 | 5259.98 | 449.632942 | 450.576071 |
| 44 | AS/RS CART | 5323.79 | 5334.8 | 456.042111 | 456.985241 |
| 45 | MACHINE CENTER 1 | 5349.28 | 5728.81 | 458.223801 | 490.719469 |
| 46 | AS/RS CART | 5385.14 | 5396.15 | 461.297424 | 462.240554 |
| 47 | MACHINE CENTER 2 | 5413.12 | 5760.946 | 463.694224 | 493.489408 |
| 48 | AS/RS CART | 5602.38 | 5613.39 | 479.906458 | 480.849588 |
| 49 | MINI-MOVER-5 | 5765.51 | 5952.938 | 493.880368 | 509.935668 |
| 50 | AS/RS CART | 5839.33 | 5850.34 | 500.203873 | 501.147003 |
| 51 | MACHINE CENTER 6 | 5850.19 | 6379.852 | 501.134154 | 546.505824 |
| 52 | AS/RS CART | 5954.83 | 5965.64 | 510.080607 | 511.023737 |
| 53 | MACHINE CENTER 3 | 5970.36 | 7160.058 | 511.428058 | 613.338987 |
| 54 | AS/RS CART | 6054.36 | 6065.37 | 518.623596 | 519.566726 |
| 55 | AS/RS CART | 6372.66 | 6383.67 | 545.889549 | 546.832678 |
| 56 | AS/RS CART | 6407.88 | 6418.88 | 548.906535 | 549.849665 |
| 57 | AS/RS CART | 6445.38 | 6456.39 | 552.118828 | 553.061959 |
| 58 | AS/RS CART | 6537.66 | 6548.67 | 560.023643 | 560.966772 |
| 59 | AS/RS CART | 6706.2 | 6717.21 | 574.460977 | 575.404107 |
| 60 | AS/RS CART | 6859.08 | 6870.09 | 587.556858 | 588.499937 |
| 61 | AS/RS CART | 6984.24 | 6995.25 | 598.278211 | 599.22134 |
| 62 | AS/RS CART | 7079.82 | 7090.83 | 606.465706 | 607.408835 |
| 63 | AS/RS CART | 7246.69 | 7257.69 | 620.759128 | 621.702259 |
| 64 | MINI-MOVER-5 | 7248.38 | 7435.788 | 620.90304 | 636.958343 |
| 65 | AS/RS CART | 7324.44 | 7335.45 | 627.420142 | 628.363272 |
| 66 | AS/RS CART | 7421.22 | 7432.23 | 635.710431 | 636.653561 |
| 67 | AS/RS CART | 7484.28 | 7495.29 | 641.112225 | 642.055354 |
| 68 | AS/RS CART | 7575 | 7586.01 | 648.883407 | 649.826536 |
| 69 | MINI-MOVER-5 | 7660.2 | 7847.628 | 656.181739 | 672.237042 |
| 70 | MACHINE CENTER 5 | 7686.12 | 8215.782 | 658.402076 | 703.773542 |
| 71 | AS/RS CART | 7744.68 | 7755.69 | 663.418395 | 664.361524 |
| 72 | AS/RS CART | 7847.34 | 7858.35 | 672.212371 | 673.155501 |
| 73 | AS/RS CART | 7891.56 | 7902.57 | 676.000308 | 676.943438 |
| 74 | AS/RS CART | 8048.16 | 8059.17 | 689.414849 | 690.357979 |
| 75 | AS/RS CART | 8340.66 | 8351.67 | 714.470743 | 715.413872 |

DECISION RULE SET= S/PT/WINQ
TIME SCALING FACTOR= 11.4768 : SIMULATION TIME= 731.311334

| NO. | FAILED COMPONENT | ACTUAL FAILING TIME | ACTUAL RECOVERY TIME | ADJUSTED FAILING TIME | ADJUSTED RECOVERY TIME |
|---|---|---|---|---|---|
| 1 | AS/RS CART | 75.744 | 86.754 | 6.59974906 | 7.5590757 |
| 2 | AS/RS CART | 151.29 | 162.3 | 13.1822459 | 14.1415728 |
| 3 | AS/RS CART | 188.91 | 199.92 | 16.4601631 | 17.4194898 |
| 4 | AS/RS CART | 387.09 | 398.07 | 33.7254267 | 34.6847534 |
| 5 | MINI-MOVER-5 | 567.336 | 754.764 | 49.4332915 | 65.7643246 |
| 6 | AS/RS CART | 810.636 | 821.646 | 70.6325806 | 71.5919072 |
| 7 | AS/RS CART | 931.874 | 942.884 | 81.1789 | 82.1382267 |
| 8 | AS/RS CART | 994.56 | 1005.57 | 86.658302 | 87.5173269 |
| 9 | MACHINE CENTER 4 | 1038.47 | 1240.[illegible] | [illegible] | [illegible] |
| 10 | AS/RS CART | 1133.35 | [illegible] | [illegible] | [illegible] |

| | | | | | |
|---|---|---|---|---|---|
| 11 | AS/RS CART | 1255.39 | 1266.37 | 109.382403 | 110.34[illegible] |
| 12 | AS/RS CART | 1292.73 | 1303.77 | 112.841154 | 113.800481 |
| 13 | AS/RS CART | 1344.59 | 1355.6 | 117.157222 | 118.115549 |
| 14 | AS/RS CART | 1386.1 | 1397.11 | 120.774083 | 121.73341 |
| 15 | AS/RS CART | 1551.55 | 1562.56 | 135.190123 | 136.148449 |
| 16 | AS/RS CART | 1720.57 | 1731.58 | 149.917224 | 150.876551 |
| 17 | AS/RS CART | 1822.37 | 1833.38 | 158.787283 | 159.746613 |
| 18 | AS/RS CART | 1914.59 | 1925.6 | 166.822834 | 167.78186 |
| 19 | AS/RS CART | 2005.98 | 2016.99 | 174.785655 | 175.744981 |
| 20 | AS/RS CART | 2111.21 | 2122.22 | 183.954587 | 184.913913 |
| 21 | AS/RS CART | 2283.37 | 2294.38 | 198.955284 | 199.91491 |
| 22 | AS/RS CART | 2561.25 | 2572.26 | 223.167809 | 224.126334 |
| 23 | AS/RS CART | 2689.37 | 2700.38 | 234.330998 | 235.290325 |
| 24 | MACHINE CENTER 2 | 2855.12 | 3202.946 | 248.773177 | 279.080057 |
| 25 | AS/RS CART | 2881.51 | 2892.52 | 251.072599 | 252.031925 |
| 26 | AS/RS CART | 3090.55 | 3101.56 | 269.288735 | 270.248062 |
| 27 | AS/RS CART | 3245.77 | 3256.78 | 282.811411 | 283.770738 |
| 28 | AS/RS CART | 3336.7 | 3347.71 | 290.734351 | 291.693673 |
| 29 | AS/RS CART | 3549.3 | 3560.31 | 309.258679 | 310.218005 |
| 30 | MACHINE CENTER 4 | 3670.76 | 3872.528 | 319.841788 | 337.422279 |
| 31 | AS/RS CART | 3806.8 | 3817.81 | 331.87782 | 332.837148 |
| 32 | AS/RS CART | 3849.08 | 3860.09 | 335.3792 | 336.338527 |
| 33 | MACHINE CENTER 5 | 3911.17 | 4440.832 | 340.793245 | 386.939914 |
| 34 | AS/RS CART | 3922.2 | 3933.21 | 341.750314 | 342.70984 |
| 35 | MINI-MOVER-5 | 3926.47 | 4115.839 | 342.298833 | 359.627669 |
| 36 | AS/RS CART | 4414.21 | 4425.22 | 384.620278 | 385.579604 |
| 37 | MACHINE CENTER 1 | 4578.37 | 4957.72 | 386.923919 | 431.877555 |
| 38 | AS/RS CART | 4649.39 | 4660.4 | 405.112052 | 408.071379 |
| 39 | AS/RS CART | 4694.17 | 4705.18 | 409.013837 | 409.973163 |
| 40 | AS/RS CART | 4769.2 | 4780.21 | 415.551373 | 416.5107 |
| 41 | AS/RS CART | 4848.47 | 4858.48 | 422.458351 | 423.417678 |
| 42 | AS/RS CART | 4890.68 | 4901.69 | 426.136205 | 427.095532 |
| 43 | AS/RS CART | 5248.97 | 5259.98 | 457.354838 | 458.314165 |
| 44 | AS/RS CART | 5323.79 | 5334.8 | 463.874077 | 464.833403 |
| 45 | MACHINE CENTER 1 | 5349.26 | 5728.61 | 466.093336 | 499.146975 |
| 46 | AS/RS CART | 5385.14 | 5396.15 | 469.218643 | 470.17897 |
| 47 | MACHINE CENTER 2 | 5413.12 | 5760.946 | 471.657805 | 501.984485 |
| 48 | AS/RS CART | 5602.38 | 5613.39 | 488.148265 | 489.107591 |
| 49 | MINI-MOVER-5 | 5765.51 | 5952.938 | 502.362157 | 518.69318 |
| 50 | AS/RS CART | 5839.33 | 5850.34 | 508.794263 | 509.75359 |
| 51 | MACHINE CENTER 6 | 5850.19 | 6378.852 | 509.74052 | 555.801189 |
| 52 | AS/RS CART | 5954.83 | 5965.84 | 518.840618 | 519.799945 |
| 53 | MACHINE CENTER 3 | 5970.36 | 7160.058 | 520.211209 | 623.872334 |
| 54 | AS/RS CART | 6054.36 | 6065.37 | 527.530322 | 528.489649 |
| 55 | AS/RS CART | 6372.66 | 6383.67 | 555.264534 | 556.223861 |
| 56 | AS/RS CART | 6407.88 | 6418.89 | 558.333334 | 559.29266 |
| 57 | AS/RS CART | 6445.38 | 6456.39 | 561.600795 | 562.560122 |
| 58 | AS/RS CART | 6537.96 | 6548.97 | 569.641364 | 570.60069 |
| 59 | AS/RS CART | 6706.2 | 6717.21 | 584.323842 | 585.283169 |
| 60 | AS/RS CART | 6859.08 | 6870.09 | 597.647428 | 598.606755 |
| 61 | AS/RS CART | 6984.24 | 6995.25 | 608.552907 | 609.512234 |
| 62 | AS/RS CART | 7079.82 | 7090.83 | 616.881013 | 617.840339 |
| 63 | AS/RS CART | 7246.83 | 7257.89 | 631.419908 | 632.379234 |
| 64 | MINI-MOVER-5 | 7248.36 | 7435.782 | 631.566291 | 647.897323 |
| 65 | AS/RS CART | 7324.44 | 7335.45 | 638.195316 | 639.154642 |
| 66 | AS/RS CART | 7421.22 | 7432.23 | 646.62798 | 647.587307 |
| 67 | AS/RS CART | 7484.28 | 7495.29 | 652.122543 | 653.08187 |
| 68 | AS/RS CART | 7575 | 7586.01 | 660.027185 | 660.986512 |
| 69 | MINI-MOVER-5 | 7660.2 | 7847.623 | 667.450858 | 683.781591 |
| 70 | MACHINE CENTER 5 | 7386.12 | 8215.782 | 689.708327 | 715.859998 |
| 71 | AS/RS CART | 7744.62 | 7755.69 | 674.811795 | 675.771121 |
| 72 | AS/RS CART | 7947.34 | 7958.35 | 693.756797 | 694.716123 |
| 73 | AS/RS CART | 7891.53 | 7902.57 | 687.603787 | 688.563113 |
| 74 | AS/RS CART | 8043.16 | 8059.17 | 701.254705 | 702.214032 |
| 75 | AS/RS CART | 8340.63 | 8351.57 | 726.742603 | 727.70023 |

DECISION RULE SET= VALUE/RANDOM
TIME SCALING FACTOR= 12.1122 ! SIMULATION TIME= 633.830153

| NO. | FAILED COMPONENT | ACTUAL FAILING TIME | ACTUAL RECOVERY TIME | ADJUSTED FAILING TIME | ADJUSTED RECOVERY TIME |
|---|---|---|---|---|---|
| 1 | AS/RS CART | 75.744 | 86.754 | 6.25456827 | 7.16371323 |
| 2 | AS/RS CART | 151.29 | 162.3 | 12.4927747 | 13.4019257 |
| 3 | AS/RS CART | 188.91 | 199.92 | 15.5982488 | 16.5083979 |
| 4 | AS/RS CART | 387.06 | 398.07 | 31.961497 | 32.870638 |
| 5 | MINI-MOVER-5 | 567.338 | 754.754 | 46.8477912 | 62.3246519 |
| 6 | AS/RS CART | 810.636 | 821.646 | 66.9382335 | 67.8474344 |
| 7 | AS/RS CART | 931.674 | 942.684 | 76.9323936 | 77.8421486 |
| 8 | AS/RS CART | 994.56 | 1005.57 | 82.1258113 | 83.0349823 |
| 9 | MACHINE CENTER 4 | 1038.47 | 1240.238 | 85.7516804 | 102.412877 |
| 10 | AS/RS CART | 1133.95 | 1144.96 | 93.6359433 | 94.5450343 |
| 11 | AS/RS CART | 1255.36 | 1266.37 | 103.661376 | 104.570527 |
| 12 | AS/RS CART | 1292.76 | 1303.77 | 106.740682 | 107.659333 |
| 13 | AS/RS CART | 1344.59 | 1355.6 | 111.028545 | 111.938696 |
| 14 | AS/RS CART | 1386.1 | 1397.11 | 114.457234 | 115.366385 |
| 15 | AS/RS CART | 1551.55 | 1562.56 | 128.119271 | 129.028422 |
| 16 | AS/RS CART | 1720.57 | 1731.58 | 142.078121 | 142.985252 |
| 17 | AS/RS CART | 1822.37 | 1833.38 | 150.482333 | 151.391383 |
| 18 | AS/RS CART | 1914.59 | 1925.6 | 158.097308 | 159.006457 |
| 19 | AS/RS CART | 2005.39 | 2016.39 | 165.643837 | 166.552983 |
| 20 | AS/RS CART | 2111.21 | 2122.22 | 174.333807 | 175.242356 |
| 21 | AS/RS CART | 2283.37 | 2294.38 | 188.549322 | 189.458473 |
| 22 | AS/RS CART | 2561.25 | 2572.26 | 211.495268 | 212.404419 |
| 23 | AS/RS CART | 2689.37 | 2700.38 | 222.07478 | 222.983831 |
| 24 | MACHINE CENTER 2 | 2855.12 | 3202.946 | 235.761585 | 264.483328 |
| 25 | AS/RS CART | 2881.51 | 2892.52 | 237.940744 | 238.849895 |
| 26 | AS/RS CART | 3090.55 | 3101.56 | 255.202226 | 256.111377 |
| 27 | AS/RS CART | 3245.77 | 3256.78 | 268.018521 | 268.928672 |
| 28 | AS/RS CART | 3336.7 | 3347.71 | 275.523067 | 276.437218 |
| 29 | AS/RS CART | 3549.3 | 3560.31 | 293.083516 | 293.992356 |
| 30 | MACHINE CENTER 4 | 3670.78 | 3872.522 | 303.113078 | 319.774075 |
| 31 | AS/RS CART | 3806.6 | 3817.61 | 314.330069 | 315.23932 |
| 32 | AS/RS CART | 3849.08 | 3860.09 | 317.837856 | 318.747007 |
| 33 | MACHINE CENTER 5 | 3911.17 | 4440.832 | 322.964939 | 366.701789 |
| 34 | AS/RS CART | 3922.2 | 3933.21 | 323.875741 | 324.784892 |
| 35 | MINI-MOVER-5 | 3928.47 | 4115.888 | 324.393486 | 339.870357 |
| 36 | AS/RS CART | 4414.21 | 4425.22 | 364.503477 | 365.412628 |
| 37 | MACHINE CENTER 1 | 4578.37 | 4957.72 | 378.058992 | 409.383825 |
| 38 | AS/RS CART | 4649.39 | 4660.4 | 383.923468 | 384.83262 |
| 39 | AS/RS CART | 4694.17 | 4705.18 | 387.621178 | 388.53033 |
| 40 | AS/RS CART | 4769.2 | 4780.21 | 393.816783 | 394.725934 |
| 41 | AS/RS CART | 4849.47 | 4859.48 | 400.362504 | 401.271655 |
| 42 | AS/RS CART | 4890.68 | 4901.69 | 403.847996 | 404.757147 |
| 43 | AS/RS CART | 5248.97 | 5259.98 | 433.4339 | 434.342551 |
| 44 | AS/RS CART | 5323.79 | 5334.8 | 439.612063 | 440.521213 |
| 45 | MACHINE CENTER 1 | 5349.26 | 5728.61 | 441.715248 | 473.040082 |
| 46 | AS/RS CART | 5385.14 | 5396.15 | 444.67804 | 445.587191 |
| 47 | MACHINE CENTER 3 | 5413.12 | 5760.946 | 446.992469 | 475.710228 |
| 48 | AS/RS CART | 5602.38 | 5613.39 | 462.616638 | 463.525788 |
| 49 | MINI-MOVER-5 | 5765.51 | 5952.938 | 476.0871 | 491.563371 |
| 50 | AS/RS CART | 5839.33 | 5850.34 | 482.182788 | 483.091933 |
| 51 | MACHINE CENTER 6 | 5950.13 | 6379.352 | 491.279553 | 526.816403 |
| 52 | AS/RS CART | 5954.63 | 5965.64 | 491.703628 | 492.612339 |
| 53 | MACHINE CENTER 3 | 5970.38 | 7160.053 | 493.002593 | 591.241323 |
| 54 | AS/RS CART | 6054.36 | 6065.37 | 499.838995 | 500.749045 |
| 55 | AS/RS CART | 6372.66 | 6383.67 | 526.222323 | 527.131574 |
| 56 | AS/RS CART | 6407.38 | 6418.39 | 529.130816 | 530.039957 |
| 57 | AS/RS CART | 6445.38 | 6456.39 | 532.227379 | 533.13653 |
| 58 | AS/RS CART | 6537.56 | 6548.57 | 539.747[illegible] | 540.75[illegible] |
| 59 | AS/RS CART | 6726.2 | 6737.21 | 555.704585 | [illegible] |

| | | | | | |
|---|---|---|---|---|---|
| 60 | AS/RS CART | 6859.05 | 6870.03 | 563.338534 | [illegible] |
| 61 | AS/RS CART | 7034.24 | [illegible] | [illegible].723754 | 577.[illegible] |
| 62 | AS/RS CART | 7079.82 | 7090.83 | 584.616274 | 585.525425 |
| 63 | AS/RS CART | 7248.83 | 7257.69 | 598.334742 | 599.303833 |
| 64 | MINI-MOVER-5 | 7249.38 | 7435.788 | 598.533488 | 614.010339 |
| 65 | AS/RS CART | 7324.44 | 7335.45 | 604.815775 | 605.724926 |
| 66 | AS/RS CART | 7421.82 | 7432.83 | 612.807386 | 613.716537 |
| 67 | AS/RS CART | 7494.28 | 7495.29 | 618.014566 | 618.923717 |
| 68 | AS/RS CART | 7575 | 7586.01 | 625.505772 | 626.414923 |
| 69 | MINI-MOVER-5 | 7660.2 | 7847.826 | 632.541164 | 648.018034 |
| 70 | MACHINE CENTER 5 | 7686.12 | 8215.782 | 634.681508 | 678.418358 |
| 71 | AS/RS CART | 7744.63 | 7755.69 | 639.517101 | 640.426252 |
| 72 | AS/RS CART | 7947.34 | 7958.35 | 647.894253 | 648.803404 |
| 73 | AS/RS CART | 7991.56 | 7902.57 | 651.64572 | 652.554871 |
| 74 | AS/RS CART | 8048.19 | 8059.17 | 664.578968 | 665.488119 |
| 75 | AS/RS CART | 8340.66 | 8351.67 | 688.730161 | 689.639313 |

DECISION RULE SET= VALUE/FMFS
TIME SCALING FACTOR= 12.1969 ; SIMULATION TIME= 688.264703

| NO. | FAILED COMPONENT | ACTUAL FAILING TIME | ACTUAL RECOVERY TIME | ADJUSTED FAILING TIME | ADJUSTED RECOVERY TIME |
|---|---|---|---|---|---|
| 1 | AS/RS CART | 75.744 | 86.754 | 6.21513828 | 7.11882738 |
| 2 | AS/RS CART | 151.29 | 162.3 | 12.4141496 | 13.3175787 |
| 3 | AS/RS CART | 188.31 | 199.92 | 15.5010708 | 16.4044998 |
| 4 | AS/RS CART | 387.06 | 398.07 | 31.7603328 | 32.6637619 |
| 5 | MINI-MOVER-5 | 567.338 | 754.764 | 46.552838 | 61.9324023 |
| 6 | AS/RS CART | 810.636 | 821.646 | 66.5169978 | 67.4204269 |
| 7 | AS/RS CART | 931.674 | 942.684 | 76.4488098 | 77.3522389 |
| 8 | AS/RS CART | 994.56 | 1005.57 | 81.6089409 | 82.5123838 |
| 9 | MACHINE CENTER 4 | 1038.47 | 1240.238 | 85.21189 | 101.768128 |
| 10 | AS/RS CART | 1133.85 | 1144.86 | 93.0466321 | 93.9500611 |
| 11 | AS/RS CART | 1255.36 | 1266.37 | 103.008369 | 103.912388 |
| 12 | AS/RS CART | 1292.76 | 1303.77 | 106.077338 | 106.981287 |
| 13 | AS/RS CART | 1344.59 | 1355.6 | 110.330785 | 111.234184 |
| 14 | AS/RS CART | 1386.1 | 1397.11 | 113.736881 | 114.840311 |
| 15 | AS/RS CART | 1551.55 | 1562.56 | 127.312534 | 128.216383 |
| 16 | AS/RS CART | 1720.57 | 1731.58 | 141.181925 | 142.085354 |
| 17 | AS/RS CART | 1822.37 | 1833.38 | 149.535157 | 150.438536 |
| 18 | AS/RS CART | 1914.59 | 1925.6 | 157.102298 | 158.005728 |
| 19 | AS/RS CART | 2005.88 | 2016.89 | 164.601334 | 165.504763 |
| 20 | AS/RS CART | 2111.21 | 2122.22 | 173.236016 | 174.139445 |
| 21 | AS/RS CART | 2283.37 | 2294.38 | 187.36266 | 188.266088 |
| 22 | AS/RS CART | 2561.25 | 2572.26 | 210.164193 | 211.067622 |
| 23 | AS/RS CART | 2689.37 | 2700.38 | 220.677121 | 221.58055 |
| 24 | MACHINE CENTER 2 | 2855.12 | 3202.948 | 234.27779 | 262.818765 |
| 25 | AS/RS CART | 2881.51 | 2892.52 | 236.44323 | 237.346559 |
| 26 | AS/RS CART | 3089.55 | 3101.56 | 253.586075 | 254.499504 |
| 27 | AS/RS CART | 3245.77 | 3256.78 | 266.332702 | 267.236131 |
| 28 | AS/RS CART | 3336.7 | 3347.71 | 273.783992 | 274.687421 |
| 29 | AS/RS CART | 3549.3 | 3560.31 | 291.238953 | 292.142382 |
| 30 | MACHINE CENTER 4 | 3670.76 | 3872.529 | 301.205393 | 317.761531 |
| 31 | AS/RS CART | 3806.6 | 3817.61 | 312.351766 | 313.255217 |
| 32 | AS/RS CART | 3849.08 | 3860.09 | 315.837493 | 316.740927 |
| 33 | MACHINE CENTER 5 | 3911.17 | 4440.832 | 320.932313 | 364.393898 |
| 34 | AS/RS CART | 3922.2 | 3933.21 | 321.837383 | 322.740912 |
| 35 | MINI-MOVER-5 | 3928.47 | 4115.896 | 322.35187 | 337.731324 |
| 36 | AS/RS CART | 4414.21 | 4425.22 | 362.209422 | 363.112851 |
| 37 | MACHINE CENTER 1 | 4578.37 | 4957.72 | 375.679623 | 406.80731 |
| 38 | AS/RS CART | 4649.39 | 4660.4 | 381.507192 | 382.410621 |
| 39 | AS/RS CART | 4694.17 | 4705.18 | 385.18163 | 386.085059 |
| 40 | AS/RS CART | 4769.2 | 4780.21 | 391.33824 | 392.241669 |
| 41 | AS/RS CART | 4843.47 | 4853.48 | 397.642755 | [illegible] |
| 42 | AS/RS CART | 4890.88 | 4901.69 | [illegible] | [illegible] |

| | | | | | |
|---|---|---|---|---|---|
| 43 | AS/RS CART | 5243.37 | 5253.38 | 432.705922 | 433.609351 |
| 44 | AS/RS CART | 5323.73 | 5334.8 | 436.845301 | 437.7[illegible] |
| 45 | MACHINE CENTER 1 | 5349.26 | 5728.61 | 438.33525 | 470.062338 |
| 46 | AS/RS CART | 5385.14 | 5396.15 | 441.879395 | 442.782834 |
| 47 | MACHINE CENTER 2 | 5413.12 | 5760.948 | 444.175303 | 472.716277 |
| 48 | AS/RS CART | 5602.38 | 5613.39 | 459.705093 | 460.608522 |
| 49 | MINI-MOVER-5 | 5765.51 | 5952.938 | 473.090778 | 488.470243 |
| 50 | AS/RS CART | 5839.33 | 5850.34 | 479.148102 | 480.051531 |
| 51 | MACHINE CENTER 6 | 5850.19 | 6379.852 | 480.033223 | 523.500808 |
| 52 | AS/RS CART | 5954.63 | 5965.64 | 488.60908 | 489.512509 |
| 53 | MACHINE CENTER 3 | 5970.36 | 7160.058 | 489.899811 | 587.520663 |
| 54 | AS/RS CART | 6054.36 | 6065.37 | 496.792458 | 497.695987 |
| 55 | AS/RS CART | 6372.66 | 6383.67 | 522.910666 | 523.814095 |
| 56 | AS/RS CART | 6407.38 | 6418.39 | 525.800655 | 526.704084 |
| 57 | AS/RS CART | 6445.38 | 6456.39 | 528.87773 | 529.791159 |
| 58 | AS/RS CART | 6537.66 | 6548.67 | 536.449795 | 537.353224 |
| 59 | AS/RS CART | 6706.2 | 6717.21 | 550.279398 | 551.182828 |
| 60 | AS/RS CART | 6859.08 | 6870.09 | 562.824016 | 563.727445 |
| 61 | AS/RS CART | 6984.24 | 6995.25 | 573.08406 | 573.987489 |
| 62 | AS/RS CART | 7079.62 | 7090.63 | 580.936303 | 581.840337 |
| 63 | AS/RS CART | 7246.68 | 7257.69 | 594.628658 | 595.532083 |
| 64 | MINI-MOVER-5 | 7248.38 | 7435.788 | 594.768512 | 610.145976 |
| 65 | AS/RS CART | 7324.44 | 7335.45 | 601.00928 | 601.91271 |
| 66 | AS/RS CART | 7421.22 | 7432.23 | 608.950595 | 609.854024 |
| 67 | AS/RS CART | 7484.28 | 7495.29 | 614.125003 | 615.028432 |
| 68 | AS/RS CART | 7575 | 7586.01 | 621.568062 | 622.472491 |
| 69 | MINI-MOVER-5 | 7660.2 | 7847.628 | 628.560175 | 643.93864 |
| 70 | MACHINE CENTER 5 | 7686.12 | 8215.782 | 630.687049 | 674.149635 |
| 71 | AS/RS CART | 7744.68 | 7755.69 | 635.492209 | 636.395638 |
| 72 | AS/RS CART | 7847.34 | 7858.35 | 643.916008 | 644.819437 |
| 73 | AS/RS CART | 7891.56 | 7902.57 | 647.544495 | 648.447924 |
| 74 | AS/RS CART | 8042.16 | 8053.17 | 660.384358 | 661.287787 |
| 75 | AS/RS CART | 8340.86 | 8351.87 | 684.395539 | 685.298968 |

DECISION RULE SET= VALUE/NINQ
TIME SCALING FACTOR= 11.8951 ; SIMULATION TIME= 706.17313

| NO. | FAILED COMPONENT | ACTUAL FAILING TIME | ACTUAL RECOVERY TIME | ADJUSTED FAILING TIME | ADJUSTED RECOVERY TIME |
|---|---|---|---|---|---|
| 1 | AS/RS CART | 75.744 | 86.754 | 6.367664 | 7.2932552! |
| 2 | AS/RS CART | 151.29 | 162.3 | 12.7186825 | 13.6442737 |
| 3 | AS/RS CART | 188.91 | 199.92 | 15.8813293 | 16.8063205 |
| 4 | AS/RS CART | 387.06 | 398.07 | 32.539449 | 33.4650403 |
| 5 | MINI-MOVER-5 | 567.336 | 754.764 | 47.6949332 | 63.4516734 |
| 6 | AS/RS CART | 810.636 | 821.646 | 68.1487335 | 69.0743243 |
| 7 | AS/RS CART | 931.674 | 942.684 | 78.3241839 | 79.2497751 |
| 8 | AS/RS CART | 994.56 | 1005.57 | 83.6108936 | 84.5364858 |
| 9 | MACHINE CENTER 4 | 1038.47 | 1240.238 | 87.3023346 | 104.264613 |
| 10 | AS/RS CART | 1133.95 | 1144.96 | 95.3291692 | 96.2547604 |
| 11 | AS/RS CART | 1255.36 | 1266.37 | 105.535893 | 106.461484 |
| 12 | AS/RS CART | 1292.76 | 1303.77 | 108.680045 | 109.605636 |
| 13 | AS/RS CART | 1344.59 | 1355.6 | 113.037301 | 113.962892 |
| 14 | AS/RS CART | 1386.1 | 1397.11 | 116.526973 | 117.452565 |
| 15 | AS/RS CART | 1551.55 | 1562.56 | 130.436262 | 131.361853 |
| 16 | AS/RS CART | 1720.57 | 1731.58 | 144.645274 | 145.570865 |
| 17 | AS/RS CART | 1822.37 | 1833.38 | 153.20342 | 154.129011 |
| 18 | AS/RS CART | 1914.58 | 1925.6 | 160.956192 | 161.881783 |
| 19 | AS/RS CART | 2005.38 | 2016.39 | 168.639188 | 169.564779 |
| 20 | AS/RS CART | 2111.21 | 2122.22 | 177.485633 | 178.411279 |
| 21 | AS/RS CART | 2283.37 | 2294.38 | 191.958874 | 192.884465 |
| 22 | AS/RS CART | 2561.25 | 2572.26 | 215.319754 | 216.245345 |
| 23 | AS/RS CART | 2689.37 | 2700.38 | 226.090575 | 227.016166 |
| 24 | MACHINE CENTER 2 | 2855.12 | 3202.949 | 240.024[illegible] | 269.[illegible] |
| 25 | AS/RS CART | [illegible] | [illegible] | [illegible] | [illegible] |
| 26 | AS/RS CART | [illegible] | [illegible] | [illegible] | [illegible] |

| | | | | | |
|---|---|---|---|---|---|
| 27 | AS/RS CART | 3245.77 | 3256.73 | 272.868138 | 273.79173 |
| 28 | AS/RS CART | 3336.7 | 3347.71 | 280.510482 | 281.436054 |
| 29 | AS/RS CART | 3549.3 | 3560.31 | 298.383368 | 299.303959 |
| 30 | MACHINE CENTER 4 | 3670.79 | 3872.526 | 308.594295 | 325.559574 |
| 31 | AS/RS CART | 3806.6 | 3817.61 | 320.014184 | 320.939715 |
| 32 | AS/RS CART | 3849.08 | 3860.09 | 323.585342 | 324.510933 |
| 33 | MACHINE CENTER 5 | 3911.17 | 4440.832 | 328.805139 | 373.332985 |
| 34 | AS/RS CART | 3922.2 | 3933.21 | 329.732411 | 330.658002 |
| 35 | MINI-MOVER-5 | 3929.47 | 4115.698 | 330.259519 | 346.018259 |
| 36 | AS/RS CART | 4414.21 | 4425.22 | 371.094821 | 372.020412 |
| 37 | MACHINE CENTER 1 | 4576.37 | 4957.72 | 384.895461 | 416.786744 |
| 38 | AS/RS CART | 4649.39 | 4660.4 | 390.865987 | 391.791578 |
| 39 | AS/RS CART | 4694.17 | 4705.18 | 394.630562 | 395.556154 |
| 40 | AS/RS CART | 4789.2 | 4790.21 | 400.938202 | 401.863793 |
| 41 | AS/RS CART | 4848.47 | 4859.48 | 407.60229 | 408.527881 |
| 42 | AS/RS CART | 4890.68 | 4901.69 | 411.15081 | 412.076401 |
| 43 | AS/RS CART | 5248.37 | 5259.38 | 441.271616 | 442.197208 |
| 44 | AS/RS CART | 5323.79 | 5334.8 | 447.561601 | 448.487192 |
| 45 | MACHINE CENTER 1 | 5349.26 | 5728.61 | 449.702819 | 481.594102 |
| 46 | AS/RS CART | 5385.14 | 5396.15 | 452.719187 | 453.644778 |
| 47 | MACHINE CENTER 2 | 5413.12 | 5780.946 | 455.071416 | 484.312532 |
| 48 | AS/RS CART | 5602.38 | 5613.39 | 470.982163 | 471.907761 |
| 49 | MINI-MOVER-5 | 5765.51 | 5952.938 | 484.69622 | 500.45296 |
| 50 | AS/RS CART | 5839.33 | 5850.34 | 490.902138 | 491.827728 |
| 51 | MACHINE CENTER 6 | 5850.19 | 6378.852 | 491.815117 | 536.342864 |
| 52 | AS/RS CART | 5954.63 | 5965.64 | 500.595203 | 501.520795 |
| 53 | MACHINE CENTER 3 | 5970.36 | 7160.058 | 501.917597 | 601.933401 |
| 54 | AS/RS CART | 6054.36 | 6065.37 | 508.979328 | 509.904918 |
| 55 | AS/RS CART | 6372.66 | 6383.67 | 535.738245 | 536.663837 |
| 56 | AS/RS CART | 6407.68 | 6418.69 | 538.698128 | 539.62472 |
| 57 | AS/RS CART | 6445.38 | 6456.39 | 541.851687 | 542.777278 |
| 58 | AS/RS CART | 6537.66 | 6548.67 | 549.609504 | 550.535085 |
| 59 | AS/RS CART | 6706.2 | 6717.21 | 563.778363 | 564.703954 |
| 60 | AS/RS CART | 6859.08 | 6870.09 | 576.630714 | 577.556305 |
| 61 | AS/RS CART | 6984.24 | 6995.25 | 587.152693 | 588.078284 |
| 62 | AS/RS CART | 7079.82 | 7090.83 | 595.187935 | 596.113526 |
| 63 | AS/RS CART | 7246.98 | 7257.69 | 609.215559 | 610.141151 |
| 64 | MINI-MOVER-5 | 7248.36 | 7435.788 | 609.356794 | 625.113534 |
| 65 | AS/RS CART | 7324.44 | 7335.45 | 615.752705 | 616.678296 |
| 66 | AS/RS CART | 7421.22 | 7432.23 | 623.888828 | 624.81442 |
| 67 | AS/RS CART | 7484.28 | 7495.29 | 629.190171 | 630.115762 |
| 68 | AS/RS CART | 7575 | 7586.01 | 636.816841 | 637.742432 |
| 69 | MINI-MOVER-5 | 7660.2 | 7847.629 | 643.979454 | 659.736194 |
| 70 | MACHINE CENTER 5 | 7686.12 | 8215.782 | 646.159503 | 690.68625 |
| 71 | AS/RS CART | 7744.68 | 7755.69 | 651.081538 | 652.007129 |
| 72 | AS/RS CART | 7847.34 | 7858.35 | 659.711983 | 660.637574 |
| 73 | AS/RS CART | 7891.56 | 7902.57 | 663.42848 | 664.355071 |
| 74 | AS/RS CART | 8048.16 | 8059.17 | 676.594564 | 677.520156 |
| 75 | AS/RS CART | 8340.66 | 8351.67 | 701.184522 | 702.110113 |

DECISION RULE SET= VALUE/WINO
TIME SCALING FACTOR= 11.736 ; SIMULATION TIME= 715.746422

| NO. | FAILED COMPONENT | ACTUAL FAILING TIME | ACTUAL RECOVERY TIME | ADJUSTED FAILING TIME | ADJUSTED RECOVERY TIME |
|---|---|---|---|---|---|
| 1 | AS/RS CART | 75.744 | 86.754 | 6.45338773 | 7.38212375 |
| 2 | AS/RS CART | 151.29 | 162.3 | 12.9311043 | 13.8292434 |
| 3 | AS/RS CART | 188.31 | 199.32 | 16.0366258 | 17.0347543 |
| 4 | AS/RS CART | 387.06 | 398.07 | 32.9805725 | 33.9187117 |
| 5 | MINI-MOVER-5 | 567.339 | 754.764 | 48.3415133 | 64.3118629 |
| 6 | AS/RS CART | 810.636 | 821.646 | 69.0725972 | 70.0107362 |
| 7 | AS/RS CART | 931.974 | 942.984 | 79.3359318 | 80.3241303 |
| 8 | AS/RS CART | 994.56 | 1005.57 | 84.7443763 | 85.6825154 |
| 9 | MACHINE CENTER 4 | [illegible] | [illegible] | [illegible] | [illegible] |
| 10 | AS/RS CART | [illegible] | [illegible] | [illegible] | [illegible] |

| | | | | | |
|---|---|---|---|---|---|
| 11 | AS/RS CART | 1255.36 | 1266.37 | 106.966596 | 107.904733 |
| 12 | AS/RS CART | 1298.76 | 1303.77 | 110.153374 | 111.091513 |
| 13 | AS/RS CART | 1344.59 | 1355.6 | 114.5697 | :15.507839 |
| 14 | AS/RS CART | 1386.1 | 1397.11 | 118.10668 | 119.044819 |
| 15 | AS/RS CART | 1551.55 | 1562.56 | 132.204329 | 133.142469 |
| 16 | AS/RS CART | 1720.57 | 1731.58 | 146.606169 | 147.544308 |
| 17 | AS/RS CART | 1822.37 | 1833.38 | 155.280334 | 156.218473 |
| 18 | AS/RS CART | 1914.59 | 1925.6 | 163.138207 | 164.076346 |
| 19 | AS/RS CART | 2005.98 | 2016.99 | 170.925358 | 171.863497 |
| 20 | AS/RS CART | 2111.21 | 2122.22 | 179.891786 | 180.829925 |
| 21 | AS/RS CART | 2283.37 | 2294.38 | 194.561179 | 195.499319 |
| 22 | AS/RS CART | 2561.25 | 2572.26 | 2:8.238753 | 219.176892 |
| 23 | AS/RS CART | 2689.37 | 2700.38 | 229.15559 | 230.093723 |
| 24 | MACHINE CENTER 2 | 2855.12 | 3202.946 | 243.2788 | 272.916326 |
| 25 | AS/RS CART | 2881.51 | 2892.52 | 245.527437 | 246.465576 |
| 26 | AS/RS CART | 3090.55 | 3101.56 | 263.339299 | 264.277437 |
| 27 | AS/RS CART | 3245.77 | 3256.78 | 276.565269 | 277.503408 |
| 28 | AS/RS CART | 3336.7 | 3347.71 | 284.313224 | 285.251363 |
| 29 | AS/RS CART | 3549.3 | 3560.31 | 302.429425 | 303.366565 |
| 30 | MACHINE CENTER 4 | 3670.76 | 3872.529 | 312.777778 | 329.970007 |
| 31 | AS/RS CART | 3806.6 | 3817.6! | 324.35242 | 325.290559 |
| 32 | AS/RS CART | 3849.08 | 3860.09 | 327.972052 | 328.910191 |
| 33 | MACHINE CENTER 5 | 3911.17 | 4440.832 | 333.262611 | 378.394001 |
| 34 | AS/RS CART | 3922.2 | 3933.21 | 334.202454 | 335.140593 |
| 35 | MINI-MOVER-5 | 3928.47 | 4115.888 | 334.736708 | 350.707055 |
| 36 | AS/RS CART | 4414.21 | 4425.22 | 376.125597 | 377.063736 |
| 37 | MACHINE CENTER 1 | 4576.37 | 4957.72 | 390.113327 | 422.436946 |
| 38 | AS/RS CART | 4649.39 | 4660.4 | 396.164792 | 397.10293! |
| 39 | AS/RS CART | 4694.17 | 4705.18 | 399.980402 | 400.91854! |
| 40 | AS/RS CART | 4769.2 | 4780.21 | 406.373552 | 407.311691 |
| 41 | AS/RS CART | 4848.47 | 4859.48 | 413.127982 | 414.06812! |
| 42 | AS/RS CART | 4890.68 | 4901.69 | 416.724608 | 417.662747 |
| 43 | AS/RS CART | 5248.97 | 5259.98 | 447.253749 | 448.191888 |
| 44 | AS/RS CART | 5323.79 | 5334.8 | 453.629005 | 454.567144 |
| 45 | MACHINE CENTER 1 | 5349.26 | 5728.81 | 455.79825 | 488.12287 |
| 46 | AS/RS CART | 5385.14 | 5396.15 | 458.85651 | 459.794649 |
| 47 | MACHINE CENTER 2 | 5413.12 | 5760.946 | 461.240827 | 490.878153 |
| 48 | AS/RS CART | 5602.38 | 5613.39 | 477.367076 | 478.3052:5 |
| 49 | MINI-MOVER-5 | 5765.51 | 5952.938 | 491.267042 | 507.23739 |
| 50 | AS/RS CART | 5839.33 | 5850.34 | 497.55709 | 498.495228 |
| 51 | MACHINE CENTER 6 | 5850.19 | 6379.352 | 498.482447 | 543.613033 |
| 52 | AS/RS CART | 5954.63 | 5965.64 | 507.381561 | 508.3197 |
| 53 | MACHINE CENTER 3 | 5970.36 | 7160.058 | 508.721882 | 610.093559 |
| 54 | AS/RS CART | 6054.36 | 6065.37 | 515.879346 | 516.817483 |
| 55 | AS/RS CART | 6372.66 | 6383.67 | 543.001023 | 543.939162 |
| 56 | AS/RS CART | 6407.88 | 6418.89 | 546.002045 | 546.940135 |
| 57 | AS/RS CART | 6445.38 | 6456.39 | 549.197342 | 550.135481 |
| 58 | AS/RS CART | 6537.66 | 6548.67 | 557.060327 | 557.998467 |
| 59 | AS/RS CART | 6706.2 | 6717.21 | 571.421268 | 572.359407 |
| 60 | AS/RS CART | 6859.08 | 6870.09 | 584.447853 | 585.385992 |
| 61 | AS/RS CART | 6984.24 | 6995.25 | 595.112475 | 596.050613 |
| 62 | AS/RS CART | 7079.82 | 7090.83 | 603.256647 | 604.194736 |
| 63 | AS/RS CART | 7246.68 | 7257.69 | 617.474438 | 618.412577 |
| 64 | MINI-MOVER-5 | 7248.36 | 7435.788 | 617.617597 | 633.597935 |
| 65 | AS/RS CART | 7324.44 | 7335.45 | 624.100205 | 625.038344 |
| 66 | AS/RS CART | 7421.22 | 7432.23 | 632.346628 | 633.284765 |
| 67 | AS/RS CART | 7484.28 | 7495.29 | 637.719837 | 638.657976 |
| 68 | AS/RS CART | 7575 | 7586.01 | 645.449898 | 646.388037 |
| 69 | MINI-MOVER-5 | 7660.2 | 7847.628 | 652.709812 | 668.67996 |
| 70 | MACHINE CENTER 5 | 7686.12 | 8215.782 | 654.9182 | 700.049592 |
| 71 | AS/RS CART | 7744.68 | 7755.69 | 659.907976 | 660.846115 |
| 72 | AS/RS CART | 7847.34 | 7858.35 | 668.65542 | 669.593559 |
| 73 | AS/RS CART | 7891.56 | 7902.57 | 672.423313 | 673.361452 |
| 74 | AS/RS CART | 8043.16 | 8059.17 | 685.766871 | 686.705011 |
| 75 | AS/RS CART | 8340.66 | 8351.67 | 710.690154 | 711.628323 |

# XVI. APPENDIX E:

## PROGRAM LISTING FOR ROBOT CONTROL SOFTWARE

```
1 cls
4 print "*******************************************"
5 print "*          robot control program          *"
7 print "*                for fms                  *"
8 print "*             random/random               *"
9 print "*******************************************"
10 dim tm(5),bd(10),du(10),rc(10),a1(70),a2(70),a3(70)
15 dim a4(70),a5(70),a6(70)
30 j=0:n=1:k=6:k1=61:m=0:rr=0:index=1
40 for i%=1 to k
50 read bd(i%)
60 bd(i%)=bd(i%)*60
70 next i%
80 for i%=1 to k:du(i%)=0:next i%
90 for i%=1 to k1
100 read a1(i%),a2(i%),a3(i%),a4(i%),a5(i%),a6(i%)
110 next i%
120 print "enter simulation time in minutes.":input ll:ll=ll*60
130 print "enter desired speed.":input s
140 print "enter lathe 1 time in minutes.":input l1:l1=l1*60
150 print "enter lathe 2 time in minutes.":input l2:l2=l2*60
160 print "enter wash time in minutes."   :input wt:wt=wt*60
170 print "enter wait delay in minutes."  :input wd:wd=wd*60
175 print "set home position and then press 0.":@set
180 print "press enter to start cycle.":input z
185 cl=16924
190 for i%=0 to 5:tm(i%)=0:next i%
195 for i%=0 to 5:poke cl-i%,tm(i%):next i%
200 poke 16526,152:poke 16527,2:y=usr(0)
240 for ii%=1 to 3:gosub 41000:next ii%
250 rr=rr+0.06*60
280 goto 440
290 @close:@reset
300 gosub 10000
310 for ii%=4 to 6:gosub 41000:next ii%
350 @close
360 gosub 10000
370 @read x,x,x,x,x,g:d=g/306
380 if d<0.5 then 390 else 600
```

```
390 m=m+1:print:print "part not present."
400 gosub 10000
410 for ii%=7 to 9:gosub 41000:next ii%
415 if index=1 then 420 else 430
420 rr=rr+0.245*60:index=0:goto 440
430 rr=rr+0.19*60
440 gosub 10000
460 tx=peek(16921)*3600+peek(16920)*60+peek(16919)
475 if tx+wd<=peek(16921)*3600+peek(16920)*60+peek(16919) then 510 else 480
480 print "executing wait delay.":gosub 10000:goto 475
510 te=(l1*j+l2*j+wt*j+rr)/sr
520 w3=peek(16921)*3600+peek(16920)*60+peek(16919)
530 print "current time", "turning cell effectivity"
540 print w3/60,te
550 goto 290
600 print:print "part present."
610 j=j+1:index=1
620 gosub 10000
630 for ii=10 to 18:gosub 41000:next ii%
670 @close
690 gosub 10000
700 for ii%=19 to 22:gosub 41000:next ii%
710 gosub 10000
750 tx=peek(16921)*3600+peek(16920)*60+peek(16919)
760 a=tx+l1
765 if a<=peek(16921)*3600+peek(16920)*60+peek(16919) then 795 else 770
770 print "machining on lathe 1 for part",j:gosub 10000:goto 765
795 gosub 10000
800 for ii%=23 to 30:gosub 41000:next ii%
840 @close
850 gosub 10000
860 for ii%=31 to 38:gosub 41000:next ii%
900 @close
910 gosub 10000
920 for ii%=39 to 42:gosub 41000:next ii%
930 gosub 10000
970 tx=peek(16921)*3600+peek(16920)*60+peek(16919)
980 b=tx+l2
985 if b<=peek(16921)*3600+peek(16920)*60+peek(16919) then 1010 else 990
990 print "machining on lathe 2 for part",j:gosub 10000:goto 985
1010 gosub 10000
1020 for ii%=43 to 50:gosub 41000:next ii%
1060 @close
1070 gosub 10000
1080 for ii%=51 to 55:gosub 41000:next ii%
1100 gosub 10000
1130 tx=peek(16921)*3600+peek(16920)*60+peek(16919)
1140 c=tx+wt
```

```
1145 if c<=peek(16921)*3600+peek(16920)*60+peek(16919) then 1170 else 1150
1150 print "washing for part",j:gosub 10000:goto 1145
1170 gosub 10000
1180 for ii=56 to 61:gosub 41000:next ii%
1200 gosub 10000
1220 v6=peek(16921)*3600+peek(16920)*60+peek(16919)
1230 rr=rr+0.749*60
1235 te=(l1*j+l2*j+wt*j+rr)/sr
1240 print "current time","turning cell effectivity"
1250 print v6/60,te
1260 gosub 10000:goto 290
10000 gosub 45000
10020 if bd(n)<=peek(16921)*3600+peek(16920)*60+peek(16919) then 20000
10050 return
20000 i%=n:print ii%
20005 read du(i%):du(i%)=du(i%)*60:rc(i%)=bd(i%)+du(i%)
20010 if 1<=ii% and ii%<=22 then 30070
20060 if 23<=ii% and ii%<=30 then 35090
20070 if 31<=ii% and ii%<=42 then 30070
20090 if 43<=ii% and ii%<=50 then 38090
20100 if 51<=ii% and ii%<=55 then 30070
20110 if ii%>=56 then 40080
20120 goto 20010
30070 if rc(i%)<=peek(16921)*3600+peek(16920)*60+peek(16919) then 30100
30080 print "mini-mover-5 failed.":goto 30070
30100 n=n+1:return
35090 if rc(i%)<=peek(16921)*3600+peek(16920)*60+peek(16919) then 35130
35100 print "mini-mover-5 failed.":goto 35090
35130 n=n+1:a=a+du(i%):return
38090 if rc(i%)<=peek(16921)*3600+peek(16920)*60+peek(16919) then 38130
38100 print "mini-mover-5 failed.":goto 38090
38130 n=n+1:b=b+du(i%):return
40080 if rc(i%)<=peek(16921)*3600+peek(16920)*60+peek(16919) then 40110
40090 print "mini-mover-5 failed.":goto 40080
40110 n=n+1:c=c+du(i%):return
41000 @step s,a1(ii%),a2(ii%),a3(ii%),a4(ii%),a5(ii%),a6(ii%)
41010 return
45000 if sr<=peek(16921)*3600+peek(16920)*60+peek(16919) then 50000
45010 return
50000 print:print "** statistical results **":print
50050 s1=0:s2=0:s3=0
50060 s1=l1*j/60:s2=l2*j/60:s3=wt*j/60:rr=rr/60:sr=sr*60
50090 print "total processing time of lathe 1 (min.)=   ",s1
50100 print "total processing time of lathe 2 (min.)=   ",s2
50110 print "total processing time of waher (min.)  =   ",s3
50120 print "total running time of mini-mover-5 (min.)= ";rr
50125 print "total number of parts processed= ",j
50128 print "total number of idles=          ",m
```

```
50130 el=sl/sr:e2=s2/sr:e3=s3/sr:e4=rr/sr
50140 eff=(sl+s2+s3+rr)/sr
50150 print "effectivity of lathe 1=       ",el
50160 print "effectivity of lathe 2=       ",e2
50170 print "effectivity of washer =       ",e3
50180 print "effectivity of mini-mover-5= ",e4
50190 print "average effectivity of tha turning cell= ",eff
50200 stop
50210 end
60000 data 46.4774
60010 data 321.829
60020 data 472.324
60030 data 593.802
60040 data 627.541
60050 data 999999999999
60100 data 0,0,0,0,0,100
60110 data 0,-532,16,0,0,0
60120 data 0,-260,-57,388,-380,0
60130 data 0,-944,911,0,0,0
60140 data 11,705,33,-13,-13,500
60150 data 0,42,-111,0,0,0
60160 data 0,-42,111,0,0,0
60170 data -11,-705,-33,13,13,0
60180 data 0,944,-911,0,0,0
60190 data 0,-42,111,0,0,0
60200 data -11,-705,-33,13,13,-20
60210 data 0,944,-911,0,0,0
60220 data 677,361,187,-360,360,0
60230 data 0,148,158,0,0,0
60240 data 0,0,0,18,-18,0
60250 data 0,0,0,0,0,100
60260 data 0,0,0,-18,18,0
60270 data 0,-148,-158,0,0,0
60280 data 82,69,178,0,0,0
60290 data 0,0,0,-33,33,0
60300 data 0,0,0,33,-33,0
60310 data -82,-69,-178,0,0,0
60320 data 160,-88,252,0,0,0
60330 data -71,0,0,0,0,0
60340 data 0,0,0,35,-35,0
60350 data 0,0,0,-35,35,0
60360 data 71,0,0,0,0,0
60370 data -160,88,-252,0,0,500
60380 data 0,148,158,0,0,0
60385 data 0,0,0,18,-18,0
60390 data 0,0,0,-18,18,-20
60400 data 0,-148,-158,0,0,0
60410 data 473,12,-11,3,-3,0
```

```
60420 data 0,137,156,0,0,0
60430 data 0,0,0,11,-11,0
60440 data 0,0,0,0,0,100
60450 data 0,0,0,-11,11,0
60460 data 0,-137,-156,0,0,0
60470 data 42,-73,97,0,0,0
60480 data 0,0,0,-35,35,0
60490 data 0,0,0,35,-35,0
60500 data -42,73,-97,0,0,0
60510 data 210,-212,149,-31,31,0
60520 data -176,0,0,0,0,0
60530 data 0,0,0,31,-31,0
60540 data 0,0,0,-31,31,0
60550 data 176,0,0,0,0,0
60560 data -210,212,-149,31,-31,500
60570 data 0,137,156,0,0,0
60580 data 0,0,0,11,-11,0
60590 data 0,0,0,-11,11,-20
60600 data 0,-137,-156,0,0,0
60610 data 413,0,0,0,0,0
60620 data 0,-403,532,342,-342,0
60630 data 0,538,-158,0,0,0
60640 data 0,-716,335,0,0,0
60650 data 578,0,0,0,0,0
60660 data 0,104,-108,-104,-104,0
60670 data 0,0,0,0,0,100
60680 data 0,-104,108,104,104,0
60690 data -2141,208,-885,15,-15,0
60700 data 15.3545
60710 data 15.3545
60720 data 15.3545
60730 data 15.3545
60740 data 15.3545
60750 data 999999999999
ready.
```

# XVII. APPENDIX F:

## PROGRAM LISTINGS FOR MODEL CONTROL SOFTWARE

```
2 open2,4,6:print#2,chr$(22)
5 open1,4:cmd1
10 print "3"
20 print "**************************************************************"
30 print "*                physical simulation for fms                 *"
40 print "*                 (random-random)-(twk)                      *"
50 print "**************************************************************"
100 dim d(30),lq(30),oq(30,5),pn(30,5),tp(77),tr(77),id(77),xx(30)
110 dim tf(77),w3(8,16),r1(77),t1(77),t$(77),dx(30),at(77),la(77)
120 dim cp(6,6),bo(70),bf(70),du(70),mn(70)
130 dra=59471:poke 59459,127
150 poke 59467, peek(59467) and 227
160 poke 59468, peek(59468) and 31 or 224
170 for i=1 to 30:d(i)=-1:lq(i)=0:dx(i)=0:xx(i)=0:next i
210 for i=1 to 30:for j=1 to 5:oq(i,j)=0:next j:next i
220 for i=1 to 30:for j=1 to 5:pn(i,j)=0:next j:next i
230 for i=1 to 77:r1(i)=0:at(i)=0:la(i)=0:next i
240 for i=1 to 77:tp(i)=0:t1(i)=0:tr(i)=0:id(i)=0:next i
250 for i=1 to 6:pp(i)=0:rt(i)=0:rr(i)=0:mo(i)=0:dt(i)=0:next i
258 for i=1 to 70:bo(i)=0:bf(i)=0:du(i)=0:next i
260 for i=1 to 7:pt(i)=0:v1(i)=0:w6(i)=0:next i
275 for i=1 to 8:df(i)=0:next i
278 for i=1 to 8:for j=1 to 16:w3(i,j)=0:next j:next i
290 t=0:f=0:tt=0:ff=0:for i=1 to 6:kk(i)=1:next i
300 n=0:sm=0:m1=0:m2=0:m3=0:m4=0:tu=0:t1=0:td=0
310 ta=0:w1=0:w4=0.05:w5=0.07:ms=0:t3=0:t5=0:t6=0:t7=0:t8=0
330 for i=1 to 7:lq(i)=5:next i
340 for i=8 to 30:lq(i)=0:next i
350 j=1
360 for i=j to 7:oq(i,j)=i+(i-j+1)*10:next i
370 j=j+1
380 if j<=5 then 360
390 j=5:jj=j-1
400 for i=jj to 1 step -1
410 oq(i,j)=jj+70-11*(jj-i)
420 next i
430 j=j-1:jj=j-1
440 if j>=2 then goto 400
441 for i=1 to 7:for j=1 to 5
442 pn(i,j)=int(oq(i,j)/11+0.6)
443 next j:next i
445 for i=1 to 77:tf(i)=999999999999:next i
```

```
450 for i=1 to 7
460 read pt(i),vl(i),al(i)
470 pt(i)=pt(i)*3600:al(i)=al(i)*3600
480 next i
490 for i=1 to 8:read w6(i):next i
492 for i=1 to 8:for j=1 to 6
494 read w3(i,j)
496 next j:next i
498 for i=1 to 7:read w3(i,16):next i
499 for i=1 to 7:read ro(i):next i
500 print "do you wish to change the status of any output?"
510 print "enter 1 for yes, 2 for no": input x
520 if x<>1 then 580
530 print "enter desired output number": input g
540 if g<32 then 560
550 print "illegal output number (must be 0-31)":goto 530
560 poke dra,g:poke dra,0:goto 500
580 print "3":print "enter simulation run time in minutes."
590 input sr:sr=sr*3600:print "initialization has been completed."
620 ti$="000000":ss=ti
630 print "simulation starting time is ",ss/3600
650 for i=1 to 70
660 read i,t$(i),mn(i),bo(i),du(i)
670 bo(i)=bo(i)*3600+ss:du(i)=du(i)*3600:bf(i)=bo(i)+du(i):next i
700 gosub 30000
720 gosub 11000
730 gosub 13000
750 gosub 40000
760 gosub 45000
770 gosub 41000
780 goto 700
10000 tm=ti:return
11000 if lq(8)>0 then 11040
11010 f=int(7*rnd(1)+1)
11012 if lq(f)<1 then 11028
11025 goto 11100
11028 qq=0
11030 for j=1 to 7:if lq(j)<1 then qq=qq+1:next j
11032 if qq=7 then 11036
11034 goto 11000
11036 gosub 40000:gosub 30000:goto 11000
11040 f=8:goto 11130
11100 if oq(f,1)>10 and oq(f,1)<20 then 11160
11110 if oq(f,1)>30 and oq(f,1)<40 then 11160
11120 if oq(f,1)>50 and oq(f,1)<60 then 11160
11130 t=int(6*rnd(1)+1)+21
11135 if lq(t)>4 then 11145
11140 kl=t-21:goto 11170
11145 pq=0
```

```
11150 for k=22 to 27:if lq(k)>4 then pq=pq+1:next k
11151 if pq=6 then 11157
11152 goto 11130
11157 if lq(30)>4 then 11159
11158 gosub 40000:goto 11000
11159 gosub 30000:goto 11157
11160 if lq(16)>4 then 11164
11162 kl=16:goto 11170
11164 if lq(30)>4 then 11168
11165 gosub 45000:goto 11000
11168 gosub 30000:goto 11164
11170 gosub 12000:return
12000 gosub 10000
12006 if tm/3600<=(ti/3600)-wl then 12010
12008 gosub 40000:goto 12006
12010 wl=0:tl(oq(f,l))=ti
12015 print "current time=";ti/3600
12020 poke dra,28:poke dra,0
12040 poke dra,f+50
12050 if peek(dra)=f+50 then 12070
12060 goto 12040
12070 poke dra,28:poke dra,0
12072 gosub 10000
12074 if tm/3600>(ti/3600)-w3(f,kl) then 12074
12080 poke dra,f:poke dra,0
12090 t5=ti:print "loading part  ";oq(f,l);"from storage";f:t6=ti-t5
12095 gosub 10000
12100 if tm/3600>(ti/3600)-w4 then 12100
12102 poke dra,f:poke dra,0
12104 gosub 10000
12106 if tm/3600>(ti/3600)-w5 then 12106
12110 poke dra,28:poke dra,0
12130 t7=ti:print "returning with";oq(f,l);"from storage";f:t8=ti-t7
12140 poke dra,50
12150 if peek(dra)=178 then 12170
12160 goto 12140
12170 poke dra,28:poke dra,0:xa=ti
12180 ta=ti-tl(oq(f,l))-(wl+w3(f,kl)+w4+w5)*3600-t6-t8
12185 n=n+1:ta=ta/3600
12190 print "fetch time is ";ta
12210 ft=ta+w3(f,kl)+w4+w5:sm=sm+ft*3600
12220 return
13000 if f=8 then 13040
13010 if oq(f,l)>10 and oq(f,l)<20 then 13500
13020 if oq(f,l)>30 and oq(f,l)<40 then 13500
13030 if oq(f,l)>50 and oq(f,l)<60 then 13500
13040 if d(16)=1 then 13070
```

```
13050 poke dra,16:poke dra,0:d(16)=d(16)*(-1)
13070 print "part";oq(f,1);"should be routed to machine center";t
13090 if t=27 then 13130
13100 if d(t-5)=1 then 13120
13110 poke dra,t-5:poke dra,0:d(t-5)=d(t-5)*(-1)
13120 if t=22 then 13170
13130 for a=t-6 to 17 step -1
13140 if d(a)=-1 then 13160
13150 poke dra,a:poke dra,0:d(a)=d(a)*(-1)
13160 next a
13170 poke dra,t+10
13180 if peek(dra)=t+10 then 13170
13190 tr(oq(f,1))=xa/3600+ro(t-21)
13200 gosub 14000
13210 gosub 16000
13220 ml=ml+1:df(f)=df(f)+1:dt(t-21)=dt(t-21)+1:return
13500 if d(16)=-1 then 13520
13510 poke dra,16:poke dra,0:d(16)=d(16)*(-1)
13520 print "part";oq(f,1);"should goto turning cell"
13530 poke dra,40:if peek(dra)=40 then 13530
13540 t=16:tr(oq(f,1))=xa/3600+ro(7)
13542 gosub 14000
13545 gosub 16000
13550 m2=m2+1:df(f)=df(f)+1:return
14000 for tt=22 to 27
14010 if lq(tt)>0 and d(tt)=-1 then 14040
14020 next tt
14030 return
14040 gosub 20100:goto 14020
16000 lq(t)=lq(t)+1:oq(t,lq(t))=oq(f,1)
16010 if lq(f)<1 then return
16020 lq(f)=lq(f)-1
16030 for j=1 to lq(f):oq(f,j)=oq(f,j+1):next j
16040 return
18000 nc=tn-21
18035 pn(tn,1)=int(oq(tn,1)/11+0.6)
18040 pp(nc)=pt(pn(tn,1))
18050 rt(nc)=rr(nc)+pp(nc):rr(nc)=rt(nc)
18060 rt(nc)=rt(nc)/3600
18070 print "total processing time of m/c";tn;"is";rt(nc)
18080 su=su+pp(nc)
18090 ms=(sm+su/6)/(2*sr):t3=ti/3600
18100 print "current time"," system effecivity  "
18110 print t3,ms
18120 for j=1 to lq(tn):cp(nc,j)=0:next j
18130 if lq(tn)<2 then 18175
18140 for j=2 to lq(tn)
```

```
18150 pn(tn,j)=int(oq(tn,j)/11+0.6)
18160 cp(nc,j+1)=cp(nc,j)+pt(pn(tn,j)):next j
18165 cp(nc,lq(tn)+1)=cp(nc,lq(tn)+1)/3600
18170 print "  remaining time of m/c queue";tn;"is";cp(nc,lq(tn)+1)
18175 if lq(tn)<1 then 18230
18180 lq(tn)=lq(tn)-1
18190 if lq(tn)<1 then 18230
18200 for j=1 to lq(tn)
18210 oq(tn,j)=oq(tn,j+1)
18220 next j
18230 return
20100 if dx(tt)=1 then return
20110 poke dra,tt:poke dra,0:d(tt)=d(tt)*(-1)
20112 id(oq(tt,1))=ti/3600-tr(oq(tt,1))
20115 print "waiting time of";oq(tt,1);"on m/c";tt-21;"is=";id(oq(tt,1))
20120 td=td+id(oq(tt,1))
20125 pn(tt,1)=int(oq(tt,1)/11+0.6)
20130 if dx(tt)=2 then return
20135 gosub 10000
20150 tf(oq(tt,1))=pt(pn(tt,1))+tm
20220 return
30000 if lq(30)<2 then return
30010 if rl(oq(30,1))=2 then 30025
30020 gosub 35000:goto 30030
30025 ff=8
30030 print "part";oq(30,1);"should return to storage";ff
30040 poke dra,60
30050 if peek(dra)<>188 then 30040
30060 if d(30)=1 then 30100
30070 poke dra,30:poke dra,0:d(30)=d(30)*(-1)
30080 gosub 10000
30090 if tm/3600>(ti/3600)-0.03 then 30090
30100 poke dra,30:poke dra,0:d(30)=d(30)*(-1)
30105 xb=ti:tp(oq(30,1))=xb-at(oq(30,1))*3600
30110 poke dra,60
30120 if peek(dra)=60 then 30110
30125 if ff=1 then 30160
30130 if d(ff+7)=1 then 30150
30140 poke dra,ff+7:poke dra,0:d(ff+7)=d(ff+7)*(-1)
30150 if ff=8 then 30295
30160 for l=ff+8 to 15
30170 if d(l)=-1 then 30190
30180 poke dra,l:poke dra,0:d(l)=d(l)*(-1)
30190 next l
30192 la(oq(30,1))=tp(oq(30,1))-al(pn(30,1))
```

```
30194 tp(oq(30,1))=tp(oq(30,1))/3600:la(oq(30,1))=la(oq(30,1))/3600
30196 print "throughput time of part    ";oq(30,1);"is=";tp(oq(30,1))
30198 print "production lateness of part";oq(30,1);"is=";la(oq(30,1))
30199 tu=tu+tp(oq(30,1)):tl=tl+la(oq(30,1))
30200 at(oq(30,1))=xb+w6(ff)*3600:at(oq(30,1))=at(oq(30,1))/3600
30230 print "arrival time of a new part ";oq(30,1);"is=";at(oq(30,1))
30295 lq(ff)=lq(ff)+1:oq(ff,lq(ff))=oq(30,1)
30300 if lq(30)<1 then return
30305 lq(30)=lq(30)-1
30308 if lq(30)<1 then return
30310 for j=1 to lq(30)
30320 oq(30,j)=oq(30,j+1)
30330 next j:return
35000 ff=oq(30,1)-(int(oq(30,1)/11+0.6))*10
35010 pn(30,1)=int(oq(30,1)/11+0.6):return
40000 if ti>=(sr+ss) then 50000
40010 for tn=22 to 27
40020 if d(tn)=-1 then 40060
40030 if lq(tn)<1 then 40060
40040 if lq(30)>4 then 40070
40050 if ti>=tf(oq(tn,1)) then 40500
40060 next tn
40070 return
40500 print "part";oq(tn,1);"is done at location";tn
40510 if dx(tn)=2 and xx(tn)<=tf(oq(tn,1)) then 40514
40512 goto 40520
40514 dx(tn)=10
40520 poke dra,tn:poke dra,0:d(tn)=d(tn)*(-1):mo(tn-21)=mo(tn-21)+1
40550 lq(30)=lq(30)+1
40560 oq(30,lq(30))=oq(tn,1)
40570 rl(oq(30,lq(30)))=1
40575 gosub 18000
40580 m3=m3+1:goto 40060
41000 for ic=1 to 70
41150 if ti>=bo(ic) then 41200
41160 if mn(ic)=0 then 41180
41170 if ti>=bf(ic) then 41400
41180 next ic:return
41200 if t$(ic)="as" then 41610
41220 tj=mn(ic)+21:pn(tj,1)=int(oq(tj,1)/11+0.6)
41230 if d(tj)=-1 then 41255
41240 bo(ic)=tf(oq(tj,1)):bf(ic)=bo(ic)+du(ic)
41250 if bo(ic)<ti then return
41255 dx(tj)=1
41260 print "machine center";tj;"fails at";bo(ic)/3600
41270 bo(ic)=bo(ic)+999999999999:return
41400 tj=mn(ic)+21:pn(tj,1)=int(oq(tj,1)/11+0.6)
41440 print "failed machine center";tj;"is repaired at";bf(ic)/3600
41450 dx(tj)=2:tf(oq(tj,1))=bf(ic)+pt(pn(tj,1)):xx(tj)=tf(oq(tj,1))
41460 bf(ic)=bf(ic)+999999999999:return
```

```
41610 print "as/rs cart fails. failure number is";ic
41620 wl=du(ic)/3600:bo(ic)=bo(ic)+999999999999:return
45000 if lq(30)>4 then return
45010 poke dra,59
45020 if peek(dra)=59 then 45040
45030 return
45040 m4=m4+1:tn=29
45050 lq(tn)=lq(tn)+1:oq(tn,lq(tn))=oq(16,1)
45060 print "part";oq(tn,1);"is done at location";tn
45070 poke dra,tn:poke dra,0:d(tn)=d(tn)*(-1)
45080 gosub 10000
45090 if tm/3600>(ti/3600)-0.04 then 45090
45100 poke dra,tn:poke dra,0:d(tn)=d(tn)*(-1)
45110 if lq(16)<1 then 45150
45120 lq(16)=lq(16)-1
45130 if lq(16)<1 then 45150
45140 for j=1 to lq(16):oq(16,j)=oq(16,j+1):next j
45150 if lq(tn)<1 then 45190
45160 lq(tn)=lq(tn)-1
45170 if lq(tn)<1 then 45190
45180 for j=1 to lq(tn):oq(tn,j)=oq(tn,j+1):next j
45190 lq(30)=lq(30)+1
45200 oq(30,lq(30))=oq(tn,1)
45210 rl(oq(30,lq(30)))=2
45220 return
50000 ea=sm/sr:ia=1-ea
50005 for kn=1 to 6:em(kn)=rt(kn)*3600/sr:next kn
50010 for kn=1 to 6:im(kn)=1-em(kn):next kn
50040 el=(em(1)+em(2)+em(3)+em(4)+em(5)+em(6))/6:it=1-el
50050 for kn=1 to 8:df(kn)=df(kn)/n:next kn
50060 ml=ml/n:m2=m2/n
50070 print "3"
50080 print:print "statistical results"
50090 print:print "  effectivity of as/rs cart=",ea
50100 print "         idle rate of as/rs cart=",ia
50110 for kn=1 to 6
50120 print " effectivity  of machine center";kn;"=";em(kn)
50130 print "   idle rate        of machine center";kn;"=";im(kn)
50140 next kn
50150 print "average effectivity  of machine center cell=";el
50160 print "average idle rate            of machine center cell=";it
50180 print:for kn=1 to 8
50190 print "fetch rate of storage area";kn;"=";df(kn)
50200 next kn
50210 for kn=1 to 6
50220 print "route rate to machine center";kn;"=";dt(kn)
50230 next kn
50250 print:print "fetch rate for machine center cell=";ml
```

```
50260 print "fetch rate for turning cell=           ";m2
50262 for kn=1 to 6
50264 print "total number of outputs from m/c";kn;"is=";mo(kn)
50266 next kn
50270 print "total number of outputs from m/cs=       ";m3
50280 print "total number of ouputs from turning cell=";m4
50285 print "total number of dispatches=              ";n
50290 print:for kn=1 to 8
50300 print "current queues of storage area  ";kn;"=";lq(kn)
50310 next kn
50320 print "current queues of retrieval gate=        ";lq(30)
50350 print "current queues of turning cell=          ";lq(16)
50360 print:for kn=22 to 27
50370 print "current queues of machine center";kn-21;"=";lq(kn)
50380 next kn
50390 print:for kn=1 to 8
50395 if lq(kn)<1 then 50435
50398 print "current queue sequence of storage area";kn
50400 for nn=1 to lq(kn)
50420 print oq(kn,nn);
50430 next nn
50432 print
50435 next kn
50440 print:for kn=22 to 27
50445 if lq(kn)<1 then 50485
50448 print "current queue sequence of m/c center";kn-21
50450 for nn=1 to lq(kn)
50470 print oq(kn,nn);
50480 next nn
50482 print
50485 next kn
50490 if lq(16)<1 then 50530
50492 print:print "current queue sequence of turning cell"
50495 for kn=1 to lq(16)
50510 print oq(16,kn);
50520 next kn
50530 print:print "current queue sequence of retrieval queue"
50535 for kn=1 to lq(30)
50550 print oq(30,kn);
50560 next kn
50570 print:print "total fetch time of as/rs=   ";sm/3600
50580 print:print "total processing time of m/c=";su/3600
50590 print:print "total throughput time(tp)=   ";tu
50600 print:print "total production lateness=   ";tl
50610 print:print "total idle time on machine centers=";td
50900 print#1,4:close1,4
50910 stop:end
```

```
51000 data 3.9159,190.38,49.9889
51050 data 6.7832,120.37,61.0484
51100 data 1.8842,92.32,31.7039
51150 data 0.9175,17.93,8.2578
51240 data 1.1797,107.86,25.3631
51290 data 13.1403,231.81,118.263
51360 data 1.6548,26.93,14.8935
51362 data 0.2501,0.2155,0.2004,0.1886,0.1842,0.1761,0.1673,0.1637
51365 data 0.1393,0.1364,0.1472,0.1618,0.1756,0.1753
51370 data 0.1304,0.1274,0.1383,0.1528,0.1666,0.1663
51375 data 0.1233,0.1204,0.1312,0.1457,0.1595,0.1593
51380 data 0.1138,0.1109,0.1217,0.1363,0.1500,0.1498
51385 data 0.1046,0.1016,0.1124,0.1270,0.1408,0.1405
51390 data 0.0993,0.0963,0.1071,0.1217,0.1355,0.1352
51395 data 0.0923,0.0893,0.1001,0.1147,0.1285,0.1282
51400 data 0.0829,0.0800,0.0908,0.1054,0.1192,0.1189
51405 data 0.1840,0.1751,0.1680,0.1585,0.1492,0.1439,0.1369
51410 data 0.2017,0.2173,0.2275,0.2327,0.2427,0.2581,0.1229
51430 data 1,as,0,6.2051,0.902
51440 data 2,as,0,12.394,0.902
51450 data 3,as,0,15.4759,0.902
51460 data 4,as,0,31.7088,0.902
51470 data 5,as,0,66.4091,0.902
51480 data 6,as,0,76.3248,0.902
51490 data 7,as,0,81.4766,0.902
51500 data 8,mc,4,85.0741,16.5293
51510 data 9,as,0,92.8954,0.902
51520 data 10,as,0,102.842,0.902
51530 data 11,as,0,105.906,0.902
51540 data 12,as,0,110.152,0.902
51550 data 13,as,0,113.553,0.902
51560 data 14,as,0,127.106,0.902
51570 data 15,as,0,140.953,0.902
51580 data 16,as,0,149.292,0.902
51590 data 17,as,0,156.848,0.902
51600 data 18,as,0,164.334,0.902
51610 data 19,as,0,172.955,0.902
51620 data 20,as,0,187.059,0.902
51630 data 21,as,0,209.823,0.902
51640 data 22,as,0,220.319,0.902
51650 data 23,mc,2,233.898,28.4947
51660 data 24,as,0,236.059,0.902
51670 data 25,as,0,253.184,0.902
51680 data 26,as,0,265.9,0.902
51690 data 27,as,0,273.35,0.902
51700 data 28,as,0,290.767,0.902
51710 data 29,mc,4,300.717,16.5293
51720 data 30,as,0,311.845,0.902
```

```
51730 data 31,as,0,315.326,0.902
51740 data 32,mc,5,320.411,43.3911
51750 data 33,as,0,321.315,0.902
51760 data 34,as,0,361.622,0.902
51770 data 35,mc,1,375.07,31.0772
51780 data 36,as,0,380.888,0.902
51790 data 37,as,0,384.557,0.902
51800 data 38,as,0,390.704,0.902
51810 data 39,as,0,397.198,0.902
51820 data 40,as,0,400.655,0.902
51830 data 41,as,0,430.008,0.902
51840 data 42,as,0,436.137,0.902
51850 data 43,mc,1,438.223,31.0772
51860 data 44,as,0,441.163,0.902
51870 data 45,mc,2,443.455,28.4947
51880 data 46,as,0,458.959,0.902
51890 data 47,as,0,478.371,0.902
51900 data 48,mc,6,479.261,43.3911
51910 data 49,as,0,487.816,0.902
51920 data 50,mc,3,489.105,97.4627
51930 data 51,as,0,495.987,0.902
51940 data 52,as,0,522.063,0.902
51950 data 53,as,0,524.948,0.902
51960 data 54,as,0,528.02,0.902
51970 data 55,as,0,535.58,0.902
51980 data 56,as,0,549.387,0.902
51990 data 57,as,0,561.911,0.902
52000 data 58,as,0,572.165,0.902
52010 data 59,as,0,579.995,0.902
52020 data 60,as,0,593.664,0.902
52030 data 61,as,0,600.304,0.902
52040 data 62,as,0,607.963,0.902
52050 data 63,as,0,613.129,0.902
52060 data 64,as,0,620.561,0.902
52070 data 65,mc,5,629.664,43.3911
52080 data 66,as,0,634.461,0.902
52090 data 67,as,0,642.872,0.902
52100 data 68,as,0,646.894,0.902
52110 data 69,as,0,659.323,0.902
52120 data 70,as,0,683.285,0.902
ready.
```

```
2 open2,4,6:print#2,chr$(22)
5 open1,4:cmd1
10 print "3"
20 print "**************************************************************"
30 print "*                  physical simulation for fms                *"
40 print "*                     (fsfs-fmfs)-(twk)                        *"
50 print "**************************************************************"
100 dim d(30),lq(30),oq(30,5),pn(30,5),tp(77),dx(30),xx(30),tr(77)
110 dim tf(77),w3(8,16),r1(77),tl(77),bo(70),bf(70),du(70),t$(70)
120 dim at(77),la(77),cp(6,6),mn(70),id(77)
130 dra=59471:poke 59459,127
150 poke 59467, peek(59467) and 227
160 poke 59468, peek(59468) and 31 or 224
170 for i=1 to 30:d(i)=-1:lq(i)=0:dx(i)=0:xx(i)=0:next i
210 for i=1 to 30:for j=1 to 5:oq(i,j)=0:next j:next i
220 for i=1 to 30:for j=1 to 5:pn(i,j)=0:next j:next i
230 for i=1 to 77:r1(i)=0:at(i)=0:la(i)=0:next i
240 for i=1 to 77:tp(i)=0:tl(i)=0:tr(i)=0:id(i)=0:next i
245 for i=1 to 6:mo(i)=0:dt(i)=0:pp(i)=0:rt(i)=0:rr(i)=0:next i
250 for i=1 to 70:bo(i)=0:bf(i)=0:du(i)=0:next i
260 for i=1 to 7:pt(i)=0:v1(i)=0:w6(i)=0:next i
275 for i=1 to 8:df(i)=0:next i
278 for i=1 to 8:for j=1 to 16:w3(i,j)=0:next j:next i
290 t=0:f=0:tt=0:ff=0
300 n=0:sm=0:m1=0:m2=0:m3=0:m4=0:tu=0:tl=0:td=0
310 ta=0:w1=0:w4=0.05:w5=0.07:ms=0:t3=0:t5=0:t6=0:t7=0:t8=0
330 for i=1 to 7:lq(i)=5:next i
340 for i=8 to 30:lq(i)=0:next i
350 j=1
360 for i=j to 7:oq(i,j)=i+(i-j+1)*10:next i
370 j=j+1
380 if j<=5 then 360
390 j=5:jj=j-1
400 for i=jj to 1 step -1
410 oq(i,j)=jj+70-11*(jj-i)
420 next i
430 j=j-1:jj=j-1
440 if j>=2 then goto 400
441 for i=1 to 7:for j=1 to 5
442 pn(i,j)=int(oq(i,j)/11+0.6)
443 next j:next i
445 for i=1 to 77:tf(i)=999999999999:next i
450 for i=1 to 7
460 read pt(i),v1(i),a1(i)
470 pt(i)=pt(i)*3600:a1(i)=a1(i)*3600
480 next i
490 for i=1 to 8:read w6(i):next i
492 for i=1 to 8:for j=1 to 6
```

```
494 read w3(i,j)
496 next j:next i
498 for i=1 to 7:read w3(i,16):next i
499 for i=1 to 7:read ro(i):next i
500 print "do you wish to change the status of any output?"
510 print "enter 1 for yes, 2 for no": input x
520 if x<>1 then 580
530 print "enter desired output number": input g
540 if g<32 then 560
550 print "illegal output number (must be 0-31)":goto 530
560 poke dra,g:poke dra,0:goto 500
580 print "3":print "enter simulation run time in minutes."
590 input sr:sr=sr*3600:print "initialization has been completed."
620 ti$="000000":ss=ti
630 print "simulation starting time is ",ss/3600
650 for i=1 to 70
660 read i,t$(i),mn(i),bo(i),du(i)
670 bo(i)=bo(i)*3600+ss:du(i)=du(i)*3600:bf(i)=bo(i)+du(i):next i
700 gosub 30000
720 gosub 11000
730 gosub 13000
750 gosub 40000
760 gosub 45000
770 gosub 41000
780 goto 700
10000 tm=ti:return
11000 if lq(8)>0 then 11040
11010 f=1
11012 if lq(f)<1 then 11028
11025 goto 11100
11028 qq=0
11030 for j=1 to 7:if lq(j)<1 then qq=qq+1:next j
11032 if qq=7 then 11036
11033 f=f+1
11034 if f<=7 then 11012
11035 goto 11000
11036 gosub 40000:gosub 30000:goto 11000
11040 f=8:goto 11130
11100 if oq(f,1)>10 and oq(f,1)<20 then 11160
11110 if oq(f,1)>30 and oq(f,1)<40 then 11160
11120 if oq(f,1)>50 and oq(f,1)<60 then 11160
11130 pq=0
11135 for k=22 to 27:if lq(k)>4 then pq=pq+1:next k
11140 if pq=6 then 11157
11145 t=22
11150 if lq(t)>4 then 11154
11152 kl=t-21:goto 11170
11154 t=t-1
```

```
11155 if t<=27 then 11150
11157 if lq(30)>4 then 11159
11158 gosub 40000:goto 11000
11159 gosub 30000:goto 11157
11160 if lq(16)>4 then 11164
11162 kl=16:goto 11170
11164 if lq(30)>4 then 11166
11165 gosub 45000:goto 11000
11166 gosub 30000:goto 11164
11170 gosub 12000:return
12000 gosub 10000
12006 if tm/3600<=(ti/3600)-wl then 12010
12008 gosub 40000:goto 12006
12010 wl=0:tl(oq(f,l))=ti
12015 print "current time=";ti/3600
12020 poke dra,28:poke dra,0
12040 poke dra,f+50
12050 if peek(dra)=f+50 then 12070
12060 goto 12040
12070 poke dra,28:poke dra,0
12072 gosub 10000
12074 if tm/3600>(ti/3600)-w3(f,kl) then 12074
12080 poke dra,f:poke dra,0
12090 t5=ti:print "loading part  ";oq(f,l);"from storage";f:t6=ti-t5
12095 gosub 10000
12100 if tm/3600>(ti/3600)-w4 then 12100
12102 poke dra,f:poke dra,0
12104 gosub 10000
12106 if tm/3600>(ti/3600)-w5 then 12106
12110 poke dra,28:poke dra,0
12130 t7=ti:print "returning with";oq(f,l);"from storage";f:t8=ti-t7
12140 poke dra,50
12150 if peek(dra)=178 then 12170
12160 goto 12140
12170 poke dra,28:poke dra,0:xa=ti
12180 ta=ti-tl(oq(f,l))-(wl+w3(f,kl)+w4+w5)*3600-t6-t8
12185 n=n+1:ta=ta/3600
12190 print "fetch time is ";ta
12200 ft=(ta+w3(f,kl)+w4+w5)*3600
12210 sm=sm+ft
12220 return
13000 if f=8 then 13040
13010 if oq(f,l)>10 and oq(f,l)<20 then 13500
13020 if oq(f,l)>30 and oq(f,l)<40 then 13500
13030 if oq(f,l)>50 and oq(f,l)<60 then 13500
13040 if d(16)=1 then 13070
13050 poke dra,16:poke dra,0:d(16)=d(16)*(-1)
13070 print "part";oq(f,l);"should be routed to machine center";t
```

```
13090 if t=27 then 13130
13100 if d(t-5)=1 then 13120
13110 poke dra,t-5:poke dra,0:d(t-5)=d(t-5)*(-1)
13120 if t=22 then 13170
13130 for a=t-6 to 17 step -1
13140 if d(a)=-1 then 13160
13150 poke dra,a:poke dra,0:d(a)=d(a)*(-1)
13160 next a
13170 poke dra,t+10
13180 if peek(dra)=t+10 then 13170
13190 tr(oq(f,1))=xa/3600+ro(t-21)
13200 gosub 14000
13210 gosub 16000
13220 ml=ml+1:df(f)=df(f)+1:dt(t-21)=dt(t-21)+1:return
13500 if d(16)=-1 then 13520
13510 poke dra,16:poke dra,0:d(16)=d(16)*(-1)
13520 print "part";oq(f,1);"should goto turning cell"
13530 poke dra,40:if peek(dra)=40 then 13530
13540 t=16:tr(oq(f,1))=xa/3600+ro(7)
13542 gosub 14000
13545 gosub 16000
13550 m2=m2+1:df(f)=df(f)+1:return
14000 for tt=22 to 27
14010 if lq(tt)>0 and d(tt)=-1 then 14040
14020 next tt
14030 return
14040 gosub 20100:goto 14020
16000 lq(t)=lq(t)+1:oq(t,lq(t))=oq(f,1)
16010 if lq(f)<1 then return
16020 lq(f)=lq(f)-1
16030 for j=1 to lq(f):oq(f,j)=oq(f,j+1):next j
16040 return
18000 nc=tn-21
18035 pn(tn,1)=int(oq(tn,1)/11+0.6)
18040 pp(nc)=pt(pn(tn,1))
18050 rt(nc)=rr(nc)+pp(nc):rr(nc)=rt(nc)
18060 rt(nc)=rt(nc)/3600
18070 print "total processing time of m/c";tn;"is";rt(nc)
18080 su=su+pp(nc)
18090 ms=(sm+su/6)/(2*sr):t3=ti/3600
18100 print "current time","system effectivity"
18110 print t3,ms
18120 for j=1 to lq(tn):cp(nc,j)=0:next j
18130 if lq(tn)<2 then 18175
18140 for j=2 to lq(tn)
18150 pn(tn,j)=int(oq(tn,j)/11+0.6)
18160 cp(nc,j+1)=cp(nc,j)+pt(pn(tn,j)):next j
18165 cp(nc,lq(tn)+1)=cp(nc,lq(tn)+1)/3600
```

```
18170 print "remaining time of m/c queue";tn;"is";cp(nc,lq(tn)+1)
18175 if lq(tn)<1 then 18230
18180 lq(tn)=lq(tn)-1
18190 if lq(tn)<1 then 18230
18200 for j=1 to lq(tn)
18210 oq(tn,j)=oq(tn,j+1)
18220 next j
18230 return
20100 if dx(tt)=1 then return
20110 poke dra,tt:poke dra,0:d(tt)=d(tt)*(-1)
20112 id(oq(tt,1))=ti/3600-tr(oq(tt,1))
20115 print "waiting time of";oq(tt,1);"on m/c";tt;"is";id(oq(tt,1))
20120 td=td+id(oq(tt,1))
20125 pn(tt,1)=int(oq(tt,1)/11+0.6)
20130 if dx(tt)=2 then return
20135 gosub 10000
20150 tf(oq(tt,1))=pt(pn(tt,1))+tm
20220 return
30000 if lq(30)<2 then return
30010 if rl(oq(30,1))=2 then 30025
30020 gosub 35000:goto 30030
30025 ff=8
30030 print "part";oq(30,1);"should return to storage";ff
30040 poke dra,60
30050 if peek(dra)<>188 then 30040
30060 if d(30)=1 then 30100
30070 poke dra,30:poke dra,0:d(30)=d(30)*(-1)
30080 gosub 10000
30090 if tm/3600>(ti/3600)-0.03 then 30090
30100 poke dra,30:poke dra,0:d(30)=d(30)*(-1)
30105 xb=ti:tp(oq(30,1))=xb-at(oq(30,1))*3600
30110 poke dra,60
30120 if peek(dra)=60 then 30110
30125 if ff=1 then 30160
30130 if d(ff+7)=1 then 30150
30140 poke dra,ff+7:poke dra,0:d(ff+7)=d(ff+7)*(-1)
30150 if ff=8 then 30295
30160 for l=ff+8 to 15
30170 if d(l)=-1 then 30190
30180 poke dra,l:poke dra,0:d(l)=d(l)*(-1)
30190 next l
30192 la(oq(30,1))=tp(oq(30,1))-al(pn(30,1))
30194 tp(oq(30,1))=tp(oq(30,1))/3600:la(oq(30,1))=la(oq(30,1))/3600
30196 print "throughput time of part    ";oq(30,1);"is=";tp(oq(30,1))
30198 print "production lateness of part";oq(30,1);"is=";la(oq(30,1))
30199 tu=tu+tp(oq(30,1)):tl=tl+la(oq(30,1))
30200 at(oq(30,1))=xb+w6(ff)*3600:at(oq(30,1))=at(oq(30,1))/3600
30230 print "arrival time of a new part ";oq(30,1);"is=";at(oq(30,1))
```

```
30295 lq(ff)=lq(ff)+1:oq(ff,lq(ff))=oq(30,1)
30300 if lq(30)<1 then return
30305 lq(30)=lq(30)-1
30308 if lq(30)<1 then return
30310 for j=1 to lq(30)
30320 oq(30,j)=oq(30,j+1)
30330 next j:return
35000 ff=oq(30,1)-(int(oq(30,1)/11+0.6))*10
35010 pn(30,1)=int(oq(30,1)/11+0.6):return
40000 if ti>=(sr+ss) then 50000
40010 for tn=22 to 27
40020 if d(tn)=-1 then 40060
40030 if lq(tn)<1 then 40060
40040 if lq(30)>4 then 40070
40050 if ti>=tf(oq(tn,1)) then 40500
40060 next tn
40070 return
40500 print "part";oq(tn,1);"is done at location";tn
40510 if dx(tn)=2 and xx(tn)<=tf(oq(tn,1)) then 40514
40512 goto 40520
40514 dx(tn)=10
40520 poke dra,tn:poke dra,0:d(tn)=d(tn)*(-1):mo(tn-21)=mo(tn-21)+1
40550 lq(30)=lq(30)+1
40560 oq(30,lq(30))=oq(tn,1)
40570 rl(oq(30,lq(30)))=1
40575 gosub 18000
40580 m3=m3+1:goto 40060
41000 for ic=1 to 70
41150 if ti>=bo(ic) then 41200
41160 if mn(ic)=0 then 41180
41170 if ti>=bf(ic) then 41400
41180 next ic:return
41200 if t$(ic)="as" then 41610
41220 tj=mn(ic)+21:pn(tj,1)=int(oq(tj,1)/11+0.6)
41230 if d(tj)=-1 then 41255
41240 bo(ic)=tf(oq(tj,1)):bf(ic)=bo(ic)+du(ic)
41250 if bo(ic)<ti then return
41255 dx(tj)=1
41260 print "machine center";tj;"fails at";bo(ic)/3600
41270 bo(ic)=bo(ic)+999999999999:return
41400 tj=mn(ic)+21:pn(tj,1)=int(oq(tj,1)/11+0.6)
41440 print "failed machine center";tj;"is repaired at";bf(ic)/3600
41450 dx(tj)=2:tf(oq(tj,1))=bf(ic)+pt(pn(tj,1)):xx(tj)=tf(oq(tj,1))
41460 bf(ic)=bf(ic)+999999999999:return
41610 print "as/rs cart fails. failure number is";ic
41620 wl=du(ic)/3600:bo(ic)=bo(ic)+999999999999:return
45000 if lq(30)>4 then return
45010 poke dra,59
```

```
45020 if peek(dra)=59 then 45040
45030 return
45040 m4=m4+1:tn=29
45050 lq(tn)=lq(tn)+1:oq(tn,lq(tn))=oq(16,1)
45060 print "part";oq(tn,1);"is done at location";tn
45070 poke dra,tn:poke dra,0:d(tn)=d(tn)*(-1)
45080 gosub 10000
45090 if tm/3600>(ti/3600)-0.04 then 45090
45100 poke dra,tn:poke dra,0:d(tn)=d(tn)*(-1)
45110 if lq(16)<1 then 45150
45120 lq(16)=lq(16)-1
45130 if lq(16)<1 then 45150
45140 for j=1 to lq(16):oq(16,j)=oq(16,j+1):next j
45150 if lq(tn)<1 then 45190
45160 lq(tn)=lq(tn)-1
45170 if lq(tn)<1 then 45190
45180 for j=1 to lq(tn):oq(tn,j)=oq(tn,j+1):next j
45190 lq(30)=lq(30)+1
45200 oq(30,lq(30))=oq(tn,1)
45210 rl(oq(30,lq(30)))=2
45220 return
50000 ea=em/sr:ia=1-ea
50005 for kn=1 to 6:em(kn)=rt(kn)*3600/sr:next kn
50010 for kn=1 to 6:im(kn)=1-em(kn):next kn
50040 el=(em(1)+em(2)+em(3)+em(4)+em(5)+em(6))/6:it=1-el
50050 for kn=1 to 8:df(kn)=df(kn)/n:next kn
50060 ml=ml/n:m2=m2/n
50070 print "3"
50080 print:print "statistical results"
50090 print:print "effectivity of as/rs cart=",ea
50100 print "idle rate of as/rs cart=",ia
50110 for kn=1 to 6
50120 print "effectivity of machine center";kn;"=";em(kn)
50130 print "idle rate of machine center";kn;"=";im(kn)
50140 next kn
50150 print "average effectivity of machine center cell=";el
50160 print "average idle rate of machine center cell=";it
50180 print:for kn=1 to 8
50190 print "fetch rate of storage area";kn;"=";df(kn)
50200 next kn
50210 for kn=1 to 6
50215 print "route rate to machine center";kn;"=";dt(kn)
50220 next kn
50250 print:print "fetch rate for machine center cell=";ml
50260 print "fetch rate for turning cell=              ";m2
50262 for kn=1 to 6
50264 print "total number of outputs from m/c";kn;"is=";mo(kn)
50266 next kn
```

```
50270 print "total number of outputs from m/cs=        ";m3
50280 print "total number of ouputs from turning cell=";m4
50285 print "total number of dispatches=               ";n
50290 print:for kn=1 to 8
50300 print "current queues of storage area  ";kn;"=";lq(kn)
50310 next kn
50320 print "current queues of retrieval gate=         ";lq(30)
50350 print "current queues of turning cell=           ";lq(16)
50360 print:for kn=22 to 27
50370 print "current queues of machine center";kn-21;"=";lq(kn)
50380 next kn
50390 print:for kn=1 to 8
50395 if lq(kn)<1 then 50435
50398 print "current queue sequence of storage area";kn
50400 for nn=1 to lq(kn)
50420 print oq(kn,nn);
50430 next nn
50432 print
50435 next kn
50440 print:for kn=22 to 27
50445 if lq(kn)<1 then 50485
50448 print "current queue sequence of m/c center";kn-21
50450 for nn=1 to lq(kn)
50470 print oq(kn,nn);
50480 next nn
50482 print
50485 next kn
50490 if lq(16)<1 then 50530
50492 print:print "current queue sequence of turning cell"
50495 for kn=1 to lq(16)
50510 print oq(16,kn);
50520 next kn
50530 print:print "current queue sequence of retrieval queue"
50535 for kn=1 to lq(30)
50550 print oq(30,kn);
50560 next kn
50570 print:print "total fetch time of as/rs=   ";sm/3600
50580 print:print "total processing time of m/c=";su/3600
50590 print:print "total throughput time(tp)=   ";tu
50600 print:print "total production lateness=   ";tl
50610 print:print "total idle time on machine centers=";td
50900 print#1,4:close1,4
50910 stop:end
51000 data 3.9307,190.38,50.1780
51050 data 6.8088,120.37,61.2794
51100 data 1.8913,92.32,31.8238
51150 data 0.9210,17.93,8.2890
51240 data 1.1841,107.86,25.4591
```

```
51290 data 13.1900,231.81,118.71
51360 data 1.6611,26.93,14.9498
51362 data 0.2501,0.2155,0.2004,0.1886,0.1842,0.1761,0.1673,0.1637
51365 data 0.1391,0.1362,0.1471,0.1617,0.1756,0.1754
51370 data 0.1301,0.1273,0.1381,0.1528,0.1667,0.1665
51375 data 0.1231,0.1202,0.1311,0.1457,0.1596,0.1594
51380 data 0.1136,0.1108,0.1216,0.1363,0.1502,0.1500
51385 data 0.1044,0.1016,0.1124,0.1271,0.1410,0.1408
51390 data 0.0992,0.0963,0.1071,0.1218,0.1357,0.1355
51395 data 0.0922,0.0893,0.1002,0.1148,0.1287,0.1285
51400 data 0.0829,0.0800,0.0909,0.1055,0.1194,0.1192
51405 data 0.1836,0.1747,0.1676,0.1582,0.1490,0.1437,0.1367
51410 data 0.2017,0.2173,0.2275,0.2327,0.2427,0.2581,0.1229
51430 data 1,as,0,6.2286,0.9115
51440 data 2,as,0,12.4409,0.9115
51450 data 3,as,0,15.5345,0.9115
51460 data 4,as,0,31.8288,0.9115
51470 data 5,as,0,66.6603,0.9115
51480 data 6,as,0,76.6135,0.9115
51490 data 7,as,0,81.7848,0.9115
51500 data 8,mc,4,85.3959,16.7033
51510 data 9,as,0,93.2468,0.9115
51520 data 10,as,0,103.231,0.9115
51530 data 11,as,0,106.306,0.9115
51540 data 12,as,0,110.568,0.9115
51550 data 13,as,0,113.982,0.9115
51560 data 14,as,0,127.587,0.9115
51570 data 15,as,0,141.486,0.9115
51580 data 16,as,0,149.857,0.9115
51590 data 17,as,0,157.441,0.9115
51600 data 18,as,0,164.956,0.9115
51610 data 19,as,0,173.609,0.9115
51620 data 20,as,0,187.766,0.9115
51630 data 21,as,0,210.617,0.9115
51640 data 22,as,0,221.152,0.9115
51650 data 23,mc,2,234.783,28.7947
51660 data 24,as,0,236.952,0.9115
51670 data 25,as,0,254.142,0.9115
51680 data 26,as,0,266.906,0.9115
51690 data 27,as,0,274.384,0.9115
51700 data 28,as,0,291.866,0.9115
51710 data 29,mc,4,301.854,16.7033
51720 data 30,as,0,313.025,0.9115
51730 data 31,as,0,316.518,0.9115
51740 data 32,mc,5,321.623,43.848
51750 data 33,as,0,322.531,0.9115
51760 data 34,as,0,362.99,0.9115
51770 data 35,mc,1,376.489,31.4044
```

```
51780 data 36,as,0,382.329,0.9115
51790 data 37,as,0,386.011,0.9115
51800 data 38,as,0,392.182,0.9115
51810 data 39,as,0,398.7,0.9115
51820 data 40,as,0,402.171,0.9115
51830 data 41,as,0,431.634,0.9115
51840 data 42,as,0,437.786,0.9115
51850 data 43,mc,1,439.881,31.4044
51860 data 44,as,0,442.832,0.9115
51870 data 45,mc,2,445.132,28.7947
51880 data 46,as,0,460.695,0.9115
51890 data 47,as,0,480.181,0.9115
51900 data 48,mc,6,481.074,43.848
51910 data 49,as,0,489.662,0.9115
51920 data 50,mc,3,490.955,98.489
51930 data 51,as,0,497.863,0.9115
51940 data 52,as,0,524.037,0.9115
51950 data 53,as,0,526.933,0.9115
51960 data 54,as,0,530.017,0.9115
51970 data 55,as,0,537.606,0.9115
51980 data 56,as,0,551.465,0.9115
51990 data 57,as,0,564.037,0.9115
52000 data 58,as,0,574.329,0.9115
52010 data 59,as,0,582.189,0.9115
52020 data 60,as,0,595.91,0.9115
52030 data 61,as,0,602.304,0.9115
52040 data 62,as,0,610.263,0.9115
52050 data 63,as,0,615.448,0.9115
52060 data 64,as,0,622.908,0.9115
52070 data 65,mc,5,632.046,43.848
52080 data 66,as,0,636.861,0.9115
52090 data 67,as,0,645.303,0.9115
52100 data 68,as,0,648.94,0.9115
52110 data 69,as,0,661.817,0.9115
52120 data 70,as,0,685.87,0.9115
ready.
```

```
2 open2,4,6:print#2,chr$(22)
5 open1,4:cmd1
10 print "3"
20 print "***************************************************************"
30 print "*                  physical simulation for fms               *"
40 print "*                        (spt-ning)-(twk)                     *"
50 print "***************************************************************"
100 dim d(30),lq(30),oq(30,5),dx(30),xx(30),pn(30,5),tp(77)
110 dim tf(77),w3(8,16),rl(77),tl(77),bo(70),bf(70),t$(70),mn(70)
120 dim la(77),at(77),cp(6,6),du(70),tr(77),id(77)
130 dra=59471:poke 59459,127
150 poke 59467, peek(59467) and 227
160 poke 59468, peek(59468) and 31 or 224
170 for i=1 to 30:d(i)=-1:lq(i)=0:dx(i)=0:xx(i)=0:next i
210 for i=1 to 30:for j=1 to 5:oq(i,j)=0:next j:next i
220 for i=1 to 30:for j=1 to 5:pn(i,j)=0:next j:next i
230 for i=1 to 77:rl(i)=0:tl(i)=0:la(i)=0:next i
240 for i=1 to 77:at(i)=0:tp(i)=0:tr(i)=0:id(i)=0:next i
245 for i=1 to 6:mo(i)=0:dt(i)=0:pp(i)=0:rt(i)=0:rr(i)=0:next i
258 for i=1 to 70:bo(i)=0:bf(i)=0:du(i)=0:next i
260 for i=1 to 7:pt(i)=0:mp(i)=0:vl(i)=0:w6(i)=0:next i
275 for i=1 to 8:df(i)=0:next i
278 for i=1 to 8:for j=1 to 16:w3(i,j)=0:next j:next i
290 t=0:f=0:tt=0:ff=0
300 n=0:mm=0:m1=0:m2=0:m3=0:m4=0:tu=0:t1=0:td=0
310 ta=0:w1=0:w4=0.05:w5=0.07:ms=0:t3=0:t5=0:t6=0:t7=0:t8=0
330 for i=1 to 7:lq(i)=5:next i
340 for i=8 to 30:lq(i)=0:next i
350 j=1
360 for i=j to 7:oq(i,j)=i+(i-j+1)*10:next i
370 j=j+1
380 if j<=5 then 360
390 j=5:jj=j-1
400 for i=jj to 1 step -1
410 oq(i,j)=jj+70-11*(jj-i)
420 next i
430 j=j-1:jj=j-1
440 if j>=2 then goto 400
441 for i=1 to 7:for j=1 to 5
442 pn(i,j)=int(oq(i,j)/11+0.6)
443 next j:next i
445 for i=1 to 77:tf(i)=999999999999:next i
450 for i=1 to 7
460 read pt(i),vl(i),al(i)
470 pt(i)=pt(i)*3600:al(i)=al(i)*3600
480 next i
490 for i=1 to 8:read w6(i):next i
492 for i=1 to 8:for j=1 to 6
```

```
494 read w3(i,j)
496 next j:next i
498 for i=1 to 7:read w3(i,16):next i
499 for i=1 to 7:read ro(i):next i
500 print "do you wish to change the status of any output?"
510 print "enter 1 for yes, 2 for no": input x
520 if x<>1 then 580
530 print "enter desired output number": input g
540 if g<32 then 560
550 print "illegal output number (must be 0-31)":goto 530
560 poke dra,g:poke dra,0:goto 500
580 print "3":print "enter simulation run time in minutes."
590 input sr:sr=sr*3600:print "initialization has been completed."
620 ti$="000000":ss=ti
630 print "simulation starting time is ",ss/3600
650 for i=1 to 70
660 read i,t$(i),mn(i),bo(i),du(i)
670 bo(i)=bo(i)*3600+ss:du(i)=du(i)*3600:bf(i)=bo(i)+du(i):next i
700 gosub 30000
720 gosub 11000
730 gosub 13000
740 gosub 40000
750 gosub 45000
770 gosub 41000
780 goto 700
10000 tm=ti:return
11000 if lq(8)>0 then 11040
11005 for j=1 to 7
11010 if lq(j)<1 then 11018
11012 pn(j,1)=int(oq(j,1)/11+0.6)
11015 if pn(j,1)=2 or pn(j,1)=4 or pn(j,1)=6 or pn(j,1)=7 then 11017
11016 mp(pn(j,1))=pt(pn(j,1))+1.6882*3600:goto 11018
11017 mp(pn(j,1))=pt(pn(j,1))
11018 next j
11020 qq=0
11021 for j=1 to 7
11022 if lq(j)<1 then qq=qq+1
11024 next j
11025 if qq=7 then 11027
11026 goto 11030
11027 gosub 40000:gosub 30000:goto 11000
11030 gosub 17000:goto 11100
11040 f=8:goto 11130
11100 if oq(f,1)>10 and oq(f,1)<20 then 11160
11110 if oq(f,1)>30 and oq(f,1)<40 then 11160
11120 if oq(f,1)>50 and oq(f,1)<60 then 11160
11130 pq=0
11135 for k=22 to 27:if lq(k)>4 then pq=pq+1:next k
```

```
11140 if pq=6 then 11157
11145 gosub 17500
11152 kl=t-21:goto 11170
11157 gosub 40000:goto 11000
11160 if lq(16)>4 then 11164
11162 kl=16:goto 11170
11164 gosub 45000:goto 11000
11170 gosub 12000:return
12000 gosub 10000
12006 if tm/3600<=(ti/3600)-w1 then 12010
12008 gosub 40000:goto 12006
12010 w1=0:tl(oq(f,1))=ti
12015 print "current time=";ti/3600
12020 poke dra,28:poke dra,0
12040 poke dra,f+50
12050 if peek(dra)=f+50 then 12070
12060 goto 12040
12070 poke dra,28:poke dra,0
12072 gosub 10000
12074 if tm/3600>(ti/3600)-w3(f,kl) then 12074
12080 poke dra,f:poke dra,0
12090 t5=ti:print "loading part  ";oq(f,1);"from storage";f:t6=ti-t5
12095 gosub 10000
12100 if tm/3600>(ti/3600)-w4 then 12100
12102 poke dra,f:poke dra,0
12104 gosub 10000
12106 if tm/3600>(ti/3600)-w5 then 12106
12110 poke dra,28:poke dra,0
12130 t7=ti:print "returning with";oq(f,1);"from storage";f:t8=ti-t7
12140 poke dra,50
12150 if peek(dra)=178 then 12170
12160 goto 12140
12170 poke dra,28:poke dra,0:xa=ti
12180 ta=ti-tl(oq(f,1))-(w1+w3(f,kl)+w4+w5)*3600-t6-t8
12185 n=n+1:ta=ta/3600
12190 print "fetch time is ";ta
12200 ft=(ta+w3(f,kl)+w4+w5)*3600
12210 sm=sm+ft
12220 return
13000 if f=8 then 13040
13010 if oq(f,1)>10 and oq(f,1)<20 then 13500
13020 if oq(f,1)>30 and oq(f,1)<40 then 13500
13030 if oq(f,1)>50 and oq(f,1)<60 then 13500
13040 if d(16)=1 then 13070
13050 poke dra,16:poke dra,0:d(16)=d(16)*(-1)
13070 print "part";oq(f,1);"should be routed to machine center";t
13090 if t=27 then 13130
13100 if d(t-5)=1 then 13120
```

```
13110 poke dra,t-5:poke dra,0:d(t-5)=d(t-5)*(-1)
13120 if t=22 then 13170
13130 for a=t-6 to 17 step -1
13140 if d(a)=-1 then 13160
13150 poke dra,a:poke dra,0:d(a)=d(a)*(-1)
13160 next a
13170 poke dra,t+10
13180 if peek(dra)=t+10 then 13170
13190 tr(oq(f,1))=xa/3600+ro(t-21)
13200 gosub 14000
13210 gosub 16000
13220 ml=ml+1:df(f)=df(f)+1:dt(t-21)=dt(t-21)+1:return
13500 if d(16)=-1 then 13520
13510 poke dra,16:poke dra,0:d(16)=d(16)*(-1)
13520 print "part";oq(f,1);"should goto turning cell"
13530 poke dra,40:if peek(dra)=40 then 13530
13540 t=16:tr(oq(f,1))=xa/3600+ro(7)
13542 gosub 14000
13545 gosub 16000
13550 m2=m2+1:df(f)=df(f)+1:return
14000 for tt=22 to 27
14010 if lq(tt)>0 and d(tt)=-1 then 14040
14020 next tt
14030 return
14040 gosub 20100:goto 14020
16000 lq(t)=lq(t)+1:oq(t,lq(t))=oq(f,1)
16010 if lq(f)<1 then return
16020 lq(f)=lq(f)-1
16030 for j=1 to lq(f):oq(f,j)=oq(f,j+1):next j
16040 return
17000 f=1
17010 if lq(f)<1 then 17110
17020 f1=f+1
17030 if f1>7 then return
17040 if lq(f1)<1 then 17060
17050 if mp(pn(f,1))>mp(pn(f1,1)) then 17100
17060 f1=f1+1
17070 if f1>7 then return
17090 goto 17040
17100 f=f1:goto 17060
17110 f=f+1
17120 if f>7 then 17000
17130 goto 17010
17500 t=22
17510 if lq(t)>4 then 17600
17520 th=t+1
17530 if th>27 then return
17540 if lq(th)>4 then 17560
```

```
17550 if lq(t)>lq(th) then 17590
17560 th=th+1
17570 if th>27 then return
17580 goto 17540
17590 t=th:goto 17560
17600 t=t+1
17610 if t>27 then 17500
17620 goto 17510
18000 nc=tn-21
18035 pn(tn,1)=int(oq(tn,1)/11+0.6)
18040 pp(nc)=pt(pn(tn,1))
18050 rt(nc)=rr(nc)+pp(nc):rr(nc)=rt(nc)
18060 rt(nc)=rt(nc)/3600
18070 print "total processing time of m/c";tn;"is";rt(nc)
18080 su=su+pp(nc)
18090 ms=(sm+su/6)/(2*sr):t3=ti/3600
18100 print "current time","system effectivity"
18110 print t3,ms
18120 for j=1 to lq(tn):cp(nc,j)=0:next j
18130 if lq(tn)<2 then 18175
18140 for j=2 to lq(tn)
18150 pn(tn,j)=int(oq(tn,j)/11+0.6)
18160 cp(nc,j+1)=cp(nc,j)+pt(pn(tn,j)):next j
18165 cp(nc,lq(tn)+1)=cp(nc,lq(tn)+1)/3600
18170 print "remaining time of m/c queue";tn;"is";cp(nc,lq(tn)+1)
18175 if lq(tn)<1 then 18230
18180 lq(tn)=lq(tn)-1
18190 if lq(tn)<1 then 18230
18200 for j=1 to lq(tn)
18210 oq(tn,j)=oq(tn,j+1)
18220 next j
18230 return
20100 if dx(tt)=1 then return
20110 poke dra,tt:poke dra,0:d(tt)=d(tt)*(-1)
20112 id(oq(tt,1))=ti/3600-tr(oq(tt,1))
20115 print "waiting time of";oq(tt,1);"on m/c";tt;"is";id(oq(tt,1))
20120 td=td+id(oq(tt,1))
20125 pn(tt,1)=int(oq(tt,1)/11+0.6)
20130 if dx(tt)=2 then return
20135 gosub 10000
20150 tf(oq(tt,1))=pt(pn(tt,1))+tm
20220 return
30000 if lq(30)<2 then return
30010 if rl(oq(30,1))=2 then 30025
30020 gosub 35000:goto 30030
30025 ff=8
30030 print "part";oq(30,1);"should return to storage";ff
30040 poke dra,60
```

```
30050 if peek(dra)<>188 then 30040
30060 if d(30)=1 then 30100
30070 poke dra,30:poke dra,0:d(30)=d(30)*(-1)
30080 gosub 10000
30090 if tm/3600>(ti/3600)-0.03 then 30090
30100 poke dra,30:poke dra,0:d(30)=d(30)*(-1)
30105 xb=ti:tp(oq(30,1))=xb-at(oq(30,1))*3600
30110 poke dra,60
30120 if peek(dra)=60 then 30110
30125 if ff=1 then 30160
30130 if d(ff+7)=1 then 30150
30140 poke dra,ff+7:poke dra,0:d(ff+7)=d(ff+7)*(-1)
30150 if ff=8 then 30295
30160 for l=ff+8 to 15
30170 if d(l)=-1 then 30190
30180 poke dra,l:poke dra,0:d(l)=d(l)*(-1)
30190 next l
30192 la(oq(30,1))=tp(oq(30,1))-al(pn(30,1))
30194 tp(oq(30,1))=tp(oq(30,1))/3600:la(oq(30,1))=la(oq(30,1))/3600
30196 print "throughput time of part    ";oq(30,1);"is=";tp(oq(30,1))
30198 print "production lateness of part";oq(30,1);"is=";la(oq(30,1))
30199 tu=tu+tp(oq(30,1)):tl=tl+la(oq(30,1))
30200 at(oq(30,1))=xb+w6(ff)*3600:at(oq(30,1))=at(oq(30,1))/3600
30230 print "arrival time of a new part ";oq(30,1);"is=";at(oq(30,1))
30295 lq(ff)=lq(ff)+1:oq(ff,lq(ff))=oq(30,1)
30300 if lq(30)<1 then return
30305 lq(30)=lq(30)-1
30308 if lq(30)<1 then return
30310 for j=1 to lq(30)
30320 oq(30,j)=oq(30,j+1)
30330 next j:return
35000 ff=oq(30,1)-(int(oq(30,1)/11+0.6))*10
35010 pn(30,1)=int(oq(30,1)/11+0.6):return
40000 if ti>=(sr+ss) then 50000
40010 for tn=22 to 27
40020 if d(tn)=-1 then 40060
40030 if lq(tn)<1 then 40060
40040 if lq(30)>4 then 40070
40050 if ti>=tf(oq(tn,1)) then 40500
40060 next tn
40070 return
40500 print "part";oq(tn,1);"is done at location";tn
40510 if dx(tn)=2 and xx(tn)<=tf(oq(tn,1)) then 40514
40512 goto 40520
40514 dx(tn)=10
40520 poke dra,tn:poke dra,0:d(tn)=d(tn)*(-1):mo(tn-21)=mo(tn-21)+1
40550 lq(30)=lq(30)+1
40560 oq(30,lq(30))=oq(tn,1)
```

```
40570 rl(oq(30,lq(30)))=1
40575 gosub 18000
40580 m3=m3+1:goto 40060
41000 for ic=1 to 70
41150 if ti>=bo(ic) then 41200
41160 if mn(ic)=0 then 41180
41170 if ti>=bf(ic) then 41400
41180 next ic:return
41200 if t$(ic)="as" then 41610
41220 tj=mn(ic)+21:pn(tj,1)=int(oq(tj,1)/11+0.6)
41230 if d(tj)=-1 then 41255
41240 bo(ic)=tf(oq(tj,1)):bf(ic)=bo(ic)+du(ic)
41250 if bo(ic)<ti then return
41255 dx(tj)=1
41260 print "machine center";tj;"fails at";bo(ic)/3600
41270 bo(ic)=bo(ic)+999999999999:return
41400 tj=mn(ic)+21:pn(tj,1)=int(oq(tj,1)/11+0.6)
41440 print "failed machine center";tj;"is repaired at";bf(ic)/3600
41450 dx(tj)=2:tf(oq(tj,1))=bf(ic)+pt(pn(tj,1)):xx(tj)=tf(oq(tj,1))
41460 bf(ic)=bf(ic)+999999999999:return
41610 print "as/re cart fails. failure number is";ic
41620 wl=du(ic)/3600:bo(ic)=bo(ic)+999999999999:return
45000 if lq(30)>4 then return
45010 poke dra,59
45020 if peek(dra)=59 then 45040
45030 return
45040 m4=m4+1:tn=29
45050 lq(tn)=lq(tn)+1:oq(tn,lq(tn))=oq(16,1)
45060 print "part";oq(tn,1);"is done at location";tn
45070 poke dra,tn:poke dra,0:d(tn)=d(tn)*(-1)
45080 gosub 10000
45090 if tm/3600>(ti/3600)-0.04 then 45090
45100 poke dra,tn:poke dra,0:d(tn)=d(tn)*(-1)
45110 if lq(16)<1 then 45150
45120 lq(16)=lq(16)-1
45130 if lq(16)<1 then 45150
45140 for j=1 to lq(16):oq(16,j)=oq(16,j+1):next j
45150 if lq(tn)<1 then 45190
45160 lq(tn)=lq(tn)-1
45170 if lq(tn)<1 then 45190
45180 for j=1 to lq(tn):oq(tn,j)=oq(tn,j+1):next j
45190 lq(30)=lq(30)+1
45200 oq(30,lq(30))=oq(tn,1)
45210 rl(oq(30,lq(30)))=2
45220 return
50000 ea=sm/sr:ia=1-ea
50005 for kn=1 to 6:em(kn)=rt(kn)*3600/sr:next kn
50010 for kn=1 to 6:im(kn)=1-em(kn):next kn
```

```
50040 el=(em(1)+em(2)+em(3)+em(4)+em(5)+em(6))/6:it=1-el
50050 for kn=1 to 8:df(kn)=df(kn)/n:next kn
50060 m1=m1/n:m2=m2/n
50070 print "3"
50080 print:print "statistical results"
50090 print:print "effectivity of as/rs cart=",ea
50100 print "idle rate of as/rs cart=",ia
50110 for kn=1 to 6
50120 print "effectivity of machine center";kn;"=";em(kn)
50130 print "idle rate of machine center";kn;"=";im(kn)
50140 next kn
50150 print "average effectivity of machine center cell=";el
50160 print "average idle rate of machine center cell=";it
50180 print:for kn=1 to 8
50190 print "fetch rate of storage area";kn;"=";df(kn)
50200 next kn
50210 for kn=1 to 6
50215 print "route rate to machine center";kn;"=";dt(kn)
50220 next kn
50250 print:print "fetch rate for machine center cell=";m1
50260 print "fetch rate for turning cell=              ";m2
50262 for kn=1 to 6
50264 print "total number of outputs from m/c";kn;"is=";mo(kn)
50266 next kn
50270 print "total number of outputs from m/cs=        ";m3
50280 print "total number of ouputs from turning cell=";m4
50285 print "total number of dispatches=               ";n
50290 print:for kn=1 to 8
50300 print "current queues of storage area  ";kn;"=";lq(kn)
50310 next kn
50320 print "current queues of retrieval gate=         ";lq(30)
50350 print "current queues of turning cell=           ";lq(16)
50360 print:for kn=22 to 27
50370 print "current queues of machine center";kn-21;"=";lq(kn)
50380 next kn
50390 print:for kn=1 to 8
50395 if lq(kn)<1 then 50435
50398 print "current queue sequence of storage area";kn
50400 for nn=1 to lq(kn)
50420 print oq(kn,nn);
50430 next nn
50432 print
50435 next kn
50440 print:for kn=22 to 27
50445 if lq(kn)<1 then 50485
50448 print "current queue sequence of m/c center";kn-21
50450 for nn=1 to lq(kn)
50470 print oq(kn,nn);
```

```
50480 next nn
50482 print
50485 next kn
50490 if lq(16)<1 then 50530
50492 print:print "current queue sequence of turning cell"
50495 for kn=1 to lq(16)
50510 print oq(16,kn);
50520 next kn
50530 print:print "current queue sequence of retrieval queue"
50535 for kn=1 to lq(30)
50550 print oq(30,kn);
50560 next kn
50570 print:print "total fetch time of as/rs=   ";sm/3600
50580 print:print "total processing time of m/c=";su/3600
50590 print:print "total throughput time(tp)=   ";tu
50600 print:print "total production lateness=   ";tl
50610 print:print "total idle time on machine centers=";td
50900 print#1,4:close1,4
50910 stop:end
51000 data 4.0349,190.38,51.5076
51050 data 6.9892,120.37,62.9031
51100 data 1.9415,92.32,32.6671
51150 data 0.9454,17.93,8.5086
51240 data 1.2155,107.86,26.1336
51290 data 13.5395,231.81,121.856
51360 data 1.7051,26.93,15.3459
51362 data 0.2501,0.2155,0.2004,0.1886,0.1842,0.1761,0.1673,0.1637
51365 data 0.1372,0.1346,0.1461,0.1612,0.1757,0.1759
51370 data 0.1285,0.1260,0.1374,0.1526,0.1671,0.1673
51375 data 0.1216,0.1191,0.1305,0.1457,0.1602,0.1604
51380 data 0.1125,0.1099,0.1213,0.1365,0.1510,0.1512
51385 data 0.1035,0.1010,0.1124,0.1276,0.1421,0.1423
51390 data 0.0984,0.0958,0.1073,0.1224,0.1369,0.1371
51395 data 0.0916,0.0890,0.1005,0.1157,0.1302,0.1304
51400 data 0.0826,0.0800,0.0914,0.1066,0.1211,0.1213
51405 data 0.1808,0.1721,0.1653,0.1561,0.1471,0.1420,0.1352
51410 data 0.2017,0.2173,0.2275,0.2327,0.2427,0.2581,0.1229
51430 data 1,as,0,6.3936,0.9294
51440 data 2,as,0,12.7705,0.9294
51450 data 3,as,0,15.9461,0.9294
51460 data 4,as,0,32.6721,0.9294
51470 data 5,as,0,68.4266,0.9294
51480 data 6,as,0,78.6435,0.9294
51490 data 7,as,0,83.9518,0.9294
51500 data 8,mc,4,87.6586,17.0314
51510 data 9,as,0,95.7175,0.9294
51520 data 10,as,0,105.966,0.9294
51530 data 11,as,0,109.123,0.9294
```

```
51540 data 12,as,0,113.498,0.9294
51550 data 13,as,0,117.002,0.9294
51560 data 14,as,0,130.968,0.9294
51570 data 15,as,0,145.235,0.9294
51580 data 16,as,0,153.828,0.9294
51590 data 17,as,0,161.613,0.9294
51600 data 18,as,0,169.327,0.9294
51610 data 19,as,0,178.209,0.9294
51620 data 20,as,0,192.742,0.9294
51630 data 21,as,0,216.198,0.9294
51640 data 22,as,0,227.012,0.9294
51650 data 23,mc,2,241.004,29.3603
51660 data 24,as,0,243.231,0.9294
51670 data 25,as,0,260.876,0.9294
51680 data 26,as,0,273.978,0.9294
51690 data 27,as,0,281.654,0.9294
51700 data 28,as,0,299.6,0.9294
51710 data 29,mc,4,309.852,17.0314
51720 data 30,as,0,321.319,0.9294
51730 data 31,as,0,324.905,0.9294
51740 data 32,mc,5,330.145,44.7093
51750 data 33,as,0,331.077,0.9294
51760 data 34,as,0,372.608,0.9294
51770 data 35,mc,1,386.464,32.0213
51780 data 36,as,0,392.459,0.9294
51790 data 37,as,0,396.239,0.9294
51800 data 38,as,0,402.573,0.9294
51810 data 39,as,0,409.265,0.9294
51820 data 40,as,0,412.827,0.9294
51830 data 41,as,0,443.071,0.9294
51840 data 42,as,0,449.386,0.9294
51850 data 43,mc,1,451.536,32.0213
51860 data 44,as,0,454.565,0.9294
51870 data 45,mc,2,456.927,29.3603
51880 data 46,as,0,472.902,0.9294
51890 data 47,as,0,492.904,0.9294
51900 data 48,mc,6,493.82,44.7093
51910 data 49,as,0,502.636,0.9294
51920 data 50,mc,3,503.964,100.4236
51930 data 51,as,0,511.054,0.9294
51940 data 52,as,0,537.923,0.9294
51950 data 53,as,0,540.896,0.9294
51960 data 54,as,0,544.061,0.9294
51970 data 55,as,0,551.85,0.9294
51980 data 56,as,0,566.077,0.9294
51990 data 57,as,0,578.982,0.9294
52000 data 58,as,0,589.547,0.9294
52010 data 59,as,0,597.615,0.9294
```

```
52020 data 60,as,0,611.699,0.9294
52030 data 61,as,0,618.263,0.9294
52040 data 62,as,0,626.432,0.9294
52050 data 63,as,0,631.755,0.9294
52060 data 64,as,0,639.413,0.9294
52070 data 65,mc,5,648.793,44.7093
52080 data 66,as,0,653.736,0.9294
52090 data 67,as,0,662.402,0.9294
52100 data 68,as,0,666.134,0.9294
52110 data 69,as,0,679.353,0.9294
52120 data 70,as,0,704.043,0.9294
ready.
```

```
2 open2,4,6:print#2,chr$(23)
5 open1,4:cmd1
10 print "3"
20 print "****************************************************************"
30 print "*                 physical simulation for fms                  *"
40 print "*                    (ddate-winq)-(twk)                        *"
50 print "****************************************************************"
100 dim d(30),lq(30),oq(30,5),dx(30),xx(30),pn(30,5),tp(77),tr(77)
110 dim tf(77),w3(8,16),rl(77),x(77),tl(77),id(77),bo(70),bf(70)
120 dim la(77),at(77),cp(6,6),dd(77),du(70),mn(70),t$(70)
130 dra=59471:poke 59459,127
150 poke 59467, peek(59467) and 227
160 poke 59468, peek(59468) and 31 or 224
170 for i=1 to 30:d(i)=-1:lq(i)=0:dx(i)=0:xx(i)=0:next i
210 for i=1 to 30:for j=1 to 5:oq(i,j)=0:next j:next i
220 for i=1 to 30:for j=1 to 5:pn(i,j)=0:next j:next i
230 for i=1 to 77:rl(i)=0:x(i)=0:tl(i)=0:la(i)=0:next i
240 for i=1 to 77:at(i)=0:tp(i)=0:dd(i)=0:tr(i)=0:id(i)=0:next i
245 for i=1 to 6:mo(i)=0:dt(i)=0:rt(i)=0:pp(i)=0:rr(i)=0:next i
258 for i=1 to 70:bo(i)=0:bf(i)=0:du(i)=0:next i
260 for i=1 to 7:pt(i)=0:vl(i)=0:w6(i)=0:next i
275 for i=1 to 8:df(i)=0:next i
278 for i=1 to 8:for j=1 to 16:w3(i,j)=0:next j:next i
290 t=0:f=0:tt=0:ff=0
300 n=0:sm=0:m1=0:m2=0:m3=0:m4=0:tu=0:t1=0:td=0
310 ta=0:w1=0:w4=0.05:w5=0.07:ms=0:t3=0:t5=0:t6=0:t7=0:t8=0
330 for i=1 to 7:lq(i)=5:next i
340 for i=8 to 30:lq(i)=0:next i
350 j=1
360 for i=j to 7:oq(i,j)=i+(i-j+1)*10:next i
370 j=j+1
380 if j<=5 then 360
390 j=5:jj=j-1
400 for i=jj to 1 step -1
410 oq(i,j)=jj+70-11*(jj-i)
420 next i
430 j=j-1:jj=j-1
440 if j>=2 then goto 400
441 for i=1 to 7:for j=1 to 5
442 pn(i,j)=int(oq(i,j)/11+0.6)
443 next j:next i
445 for i=1 to 77:tf(i)=999999999999:next i
450 for i=1 to 7
460 read pt(i),vl(i),al(i)
470 pt(i)=pt(i)*3600:al(i)=al(i)*3600
480 next i
490 for i=1 to 8:read w6(i):next i
492 for i=1 to 8:for j=1 to 6
```

```
494 read w3(i,j)
496 next j:next i
498 for i=1 to 7:read w3(i,16):next i
499 for i=1 to 7:read ro(i):next i
500 print "do you wish to change the status of any output?"
510 print "enter 1 for yes, 2 for no": input x
520 if x<>1 then 580
530 print "enter desired output number": input g
540 if g<32 then 560
550 print "illegal output number (must be 0-31)":goto 530
560 poke dra,g:poke dra,0:goto 500
580 print "3":print "enter simulation run time in minutes."
590 input sr:sr=sr*3600:print "initialization has been completed."
620 ti$="000000":ss=ti
630 print "simulation starting time is ",ss/3600
650 for i=1 to 70
660 read i,t$(i),mn(i),bo(i),du(i)
670 bo(i)=bo(i)*3600+ss:du(i)=du(i)*3600:bf(i)=bo(i)+du(i):next i
700 gosub 30000
710 gosub 18500
720 gosub 11000
730 gosub 13000
740 gosub 40000
750 gosub 45000
770 gosub 41000
780 goto 700
10000 tm=ti:return
11000 if lq(8)>0 then 11040
11005 for j=1 to 7
11010 if lq(j)<1 then 11015
11012 pn(j,1)=int(oq(j,1)/11+0.6)
11015 next j
11018 qq=0
11020 for j=1 to 7
11022 if lq(j)<1 then qq=qq+1
11024 next j
11026 if qq=7 then 11028
11027 goto 11030
11028 gosub 40000:gosub 30000:goto 11000
11030 gosub 17000:goto 11100
11040 f=8:goto 11130
11100 if oq(f,1)>10 and oq(f,1)<20 then 11160
11110 if oq(f,1)>30 and oq(f,1)<40 then 11160
11120 if oq(f,1)>50 and oq(f,1)<60 then 11160
11130 pq=0
11135 for k=22 to 27:if lq(k)>4 then pq=pq+1:next k
11140 if pq=6 then 11157
11145 gosub 17500
```

```
11152 kl=t-21·goto 11170
11157 gosub 40000:goto 11000
11160 if lq(16)>4 then 11164
11162 kl=16:goto 11170
11164 gosub 45000:goto 11000
11170 gosub 12000:return
12000 gosub 10000
12006 if tm/3600<=(ti/3600)-wl then 12010
12008 gosub 40000:goto 12006
12010 wl=0:tl(oq(f,l))=ti
12015 print "current time=";ti/3600
12020 poke dra,28:poke dra,0
12040 poke dra,f+50
12050 if peek(dra)=f+50 then 12070
12060 goto 12040
12070 poke dra,28:poke dra,0
12072 gosub 10000
12074 if tm/3600>(ti/3600)-w3(f,kl) then 12074
12080 poke dra,f:poke dra,0
12090 t5=ti:print "loading part  ";oq(f,l);"from storage";f:t6=ti-t5
12095 gosub 10000
12100 if tm/3600>(ti/3600)-w4 then 12100
12102 poke dra,f:poke dra,0
12104 gosub 10000
12106 if tm/3600>(ti/3600)-w5 then 12106
12110 poke dra,28:poke dra,0
12130 t7=ti:print "returning with";oq(f,l);"from storage";f:t8=ti-t7
12140 poke dra,50
12150 if peek(dra)=178 then 12170
12160 goto 12140
12170 poke dra,28:poke dra,0:xa=ti
12180 ta=ti-tl(oq(f,l))-(wl+w3(f,kl)+w4+w5)*3600-t6-t8
12185 n=n+1:ta=ta/3600
12190 print "fetch time is ";ta
12200 ft=(ta+w3(f,kl)+w4+w5)*3600
12210 sm=sm+ft
12220 return
13000 if f=8 then 13040
13010 if oq(f,l)>10 and oq(f,l)<20 then 13500
13020 if oq(f,l)>30 and oq(f,l)<40 then 13500
13030 if oq(f,l)>50 and oq(f,l)<60 then 13500
13040 if d(16)=1 then 13070
13050 poke dra,16:poke dra,0:d(16)=d(16)*(-1)
13070 print "part";oq(f,l);"should be routed to machine center";t
13090 if t=27 then 13130
13100 if d(t-5)=1 then 13120
13110 poke dra,t-5:poke dra,0:d(t-5)=d(t-5)*(-1)
13120 if t=22 then 13170
```

```
13130 for a=t-6 to 17 step -1
13140 if d(a)=-1 then 13160
13150 poke dra,a:poke dra,0:d(a)=d(a)*(-1)
13160 next a
13170 poke dra,t+10
13180 if peek(dra)=t+10 then 13170
13190 tr(oq(f,1))=xa/3600+ro(t-21)
13200 gosub 14000
13210 gosub 16000
13220 m1=m1+1:df(f)=df(f)+1:dt(t-21)=dt(t-21)+1:return
13500 if d(16)=-1 then 13520
13510 poke dra,16:poke dra,0:d(16)=d(16)*(-1)
13520 print "part";oq(f,1);"should goto turning cell"
13530 poke dra,40:if peek(dra)=40 then 13530
13540 t=16:tr(oq(f,1))=xa/3600+ro(7)
13542 gosub 14000
13545 gosub 16000
13550 m2=m2+1:df(f)=df(f)+1:return
14000 for tt=22 to 27
14010 if lq(tt)>0 and d(tt)=-1 then 14040
14020 next tt
14030 return
14040 gosub 20100:goto 14020
16000 lq(t)=lq(t)+1:oq(t,lq(t))=oq(f,1)
16010 if lq(f)<1 then return
16020 lq(f)=lq(f)-1
16030 for j=1 to lq(f):oq(f,j)=oq(f,j+1):next j
16040 return
17000 for j=1 to 7
17010 if lq(j)<1 then 17050
17020 if df(j)>=5 then 17040
17030 x(oq(j,1))=0:goto 17050
17040 x(oq(j,1))=1
17050 next j
17060 f=1
17070 if lq(f)<1 then 17190
17080 f1=f+1
17090 if f1>7 then return
17100 if lq(f1)<1 then 17140
17110 dd(oq(f,1))=al(pn(f,1))+x(oq(f,1))*at(oq(f,1))*3600
17120 dd(oq(f1,1))=al(pn(f1,1))+x(oq(f1,1))*at(oq(f1,1))*3600
17130 if dd(oq(f,1))>dd(oq(f1,1)) then 17180
17140 f1=f1+1
17150 if f1>7 then return
17170 goto 17100
17180 f=f1:goto 17140
17190 f=f+1
17200 if f>7 then 17060
```

```
17210 goto 17070
17500 for j=22 to 27
17510 if lq(j)>4 then cp(j-21,lq(j)+1)=999999999999
17520 next j
17530 t=22
17540 th=t+1
17550 if cp(t-21,lq(t)+1)>cp(th-21,lq(th)+1) then 17590
17560 th=th+1
17570 if th<=27 then 17550
17580 return
17590 t=th:goto 17560
18000 nc=tn-21
18035 pn(tn,1)=int(oq(tn,1)/11+0.6)
18040 pp(nc)=pt(pn(tn,1))
18050 rt(nc)=rr(nc)+pp(nc):rr(nc)=rt(nc)
18060 rt(nc)=rt(nc)/3600
18070 print "total processing time of m/c";tn;"is";rt(nc)
18080 su=su+pp(nc)
18090 ms=(sm+su/6)/(2*sr):t3=ti/3600
18100 print "current time","system effectivity"
18110 print t3,ms
18120 if lq(tn)<1 then 18180
18130 lq(tn)=lq(tn)-1
18140 if lq(tn)<1 then 18180
18150 for j=1 to lq(tn)
18160 oq(tn,j)=oq(tn,j+1)
18170 next j
18180 return
18500 for jj=22 to 27
18510 for j=1 to lq(jj)
18520 cp(jj-21,j)=0
18530 next j
18540 next jj
18550 for jj=22 to 27
18555 if lq(jj)<1 then 18610
18560 for j=1 to lq(jj)
18570 pn(jj,j)=int(oq(jj,j)/11+0.6)
18580 cp(jj-21,j+1)=cp(jj-21,j)+pt(pn(jj,j))
18590 next j
18600 cp(jj-21,lq(tn)+1)=cp(jj-21,lq(tn)+1)/3600
18610 next jj
18620 return
20100 if dx(tt)=1 then return
20110 poke dra,tt:poke dra,0:d(tt)=d(tt)*(-1)
20112 id(oq(tt,1))=ti/3600-tr(oq(tt,1))
20115 print "waiting time of";oq(tt,1);"on m/c";tt;"is";id(oq(tt,1))
20120 td=td+id(oq(tt,1))
20125 pn(tt,1)=int(oq(tt,1)/11+0.6)
```

```
20130 if dx(tt)=2 then return
20135 gosub 10000
20150 tf(oq(tt,1))=pt(pn(tt,1))+tm
20220 return
30000 if lq(30)<2 then return
30010 if rl(oq(30,1))=2 then 30025
30020 gosub 35000:goto 30030
30025 ff=8
30030 print "part";oq(30,1);"should return to storage";ff
30040 poke dra,60
30050 if peek(dra)<>188 then 30040
30060 if d(30)=1 then 30100
30070 poke dra,30:poke dra,0:d(30)=d(30)*(-1)
30080 gosub 10000
30090 if tm/3600>(ti/3600)-0.03 then 30090
30100 poke dra,30:poke dra,0:d(30)=d(30)*(-1)
30105 xb=ti:tp(oq(30,1))=xb-at(oq(30,1))*3600
30110 poke dra,60
30120 if peek(dra)=60 then 30110
30125 if ff=1 then 30160
30130 if d(ff+7)=1 then 30150
30140 poke dra,ff+7:poke dra,0:d(ff+7)=d(ff+7)*(-1)
30150 if ff=8 then 30295
30160 for l=ff+8 to 15
30170 if d(l)=-1 then 30190
30180 poke dra,l:poke dra,0:d(l)=d(l)*(-1)
30190 next l
30192 la(oq(30,1))=tp(oq(30,1))-al(pn(30,1))
30194 tp(oq(30,1))=tp(oq(30,1))/3600:la(oq(30,1))=la(oq(30,1))/3600
30196 print "throughput time of part    ";oq(30,1);"is=";tp(oq(30,1))
30198 print "production lateness of part";oq(30,1);"is=";la(oq(30,1))
30199 tu=tu+tp(oq(30,1)):tl=tl+la(oq(30,1))
30200 at(oq(30,1))=xb+w6(ff)*3600:at(oq(30,1))=at(oq(30,1))/3600
30230 print "arrival time of new part  ";oq(30,1);"is=";at(oq(30,1))
30295 lq(ff)=lq(ff)+1:oq(ff,lq(ff))=oq(30,1)
30300 if lq(30)<1 then return
30305 lq(30)=lq(30)-1
30308 if lq(30)<1 then return
30310 for j=1 to lq(30)
30320 oq(30,j)=oq(30,j+1)
30330 next j:return
35000 ff=oq(30,1)-(int(oq(30,1)/11+0.6))*10
35010 pn(30,1)=int(oq(30,1)/11+0.6):return
40000 if ti>=(sr+ss) then 50000
40010 for tn=22 to 27
40020 if d(tn)=-1 then 40060
40030 if lq(tn)<1 then 40060
40040 if lq(30)>4 then 40070
```

```
40050 if ti>=tf(oq(tn,1)) then 40500
40060 next tn
40070 return
40500 print "part";oq(tn,1);"is done at location";tn
40510 if dx(tn)=2 and xx(tn)<=tf(oq(tn,1)) then 40514
40512 goto 40520
40514 dx(tn)=10
40520 poke dra,tn:poke dra,0:d(tn)=d(tn)*(-1):mo(tn-21)=mo(tn-21)+1
40550 lq(30)=lq(30)+1
40560 oq(30,lq(30))=oq(tn,1)
40570 rl(oq(30,lq(30)))=1
40575 gosub 18000
40580 m3=m3+1:goto 40060
41000 for ic=1 to 70
41150 if ti>=bo(ic) then 41200
41160 if mn(ic)=0 then 41180
41170 if ti>=bf(ic) then 41400
41180 next ic:return
41200 if t$(ic)="as" then 41610
41220 tj=mn(ic)+21:pn(tj,1)=int(oq(tj,1)/11+0.6)
41230 if d(tj)=-1 then 41255
41240 bo(ic)=tf(oq(tj,1)):bf(ic)=bo(ic)+du(ic)
41250 if bo(ic)<ti then return
41255 dx(tj)=1
41260 print "machine center";tj;"fails at";bo(ic)/3600
41270 bo(ic)=bo(ic)+999999999999:return
41400 tj=mn(ic)+21:pn(tj,1)=int(oq(tj,1)/11+0.6)
41440 print "failed machine center";tj;"is repaired at";bf(ic)/3600
41450 dx(tj)=2:tf(oq(tj,1))=bf(ic)+pt(pn(tj,1)):xx(tj)=tf(oq(tj,1))
41460 bf(ic)=bf(ic)+999999999999:return
41610 print "as/rs cart fails. failure number is";ic
41620 wl=du(ic)/3600:bo(ic)=bo(ic)+999999999999:return
45000 if lq(30)>4 then return
45010 poke dra,59
45020 if peek(dra)=59 then 45040
45030 return
45040 m4=m4+1:tn=29
45050 lq(tn)=lq(tn)+1:oq(tn,lq(tn))=oq(16,1)
45060 print "part";oq(tn,1);"is done at location";tn
45070 poke dra,tn:poke dra,0:d(tn)=d(tn)*(-1)
45080 gosub 10000
45090 if tm/3600>(ti/3600)-0.04 then 45090
45100 poke dra,tn:poke dra,0:d(tn)=d(tn)*(-1)
45110 if lq(16)<1 then 45150
45120 lq(16)=lq(16)-1
45130 if lq(16)<1 then 45150
45140 for j=1 to lq(16):oq(16,j)=oq(16,j+1):next j
45150 if lq(tn)<1 then 45190
```

```
45160 lq(tn)=lq(tn)-1
45170 if lq(tn)<1 then 45190
45180 for j=1 to lq(tn):oq(tn,j)=oq(tn,j+1):next j
45190 lq(30)=lq(30)+1
45200 oq(30,lq(30))=oq(tn,1)
45210 rl(oq(30,lq(30)))=2
45220 return
50000 ea=sm/sr:ia=1-ea
50005 for kn=1 to 6:em(kn)=rt(kn)*3600/sr:next kn
50010 for kn=1 to 6:im(kn)=1-em(kn):next kn
50040 el=(em(1)+em(2)+em(3)+em(4)+em(5)+em(6))/6:it=1-el
50050 for kn=1 to 8:df(kn)=df(kn)/n:next kn
50060 ml=ml/n:m2=m2/n
50070 print "3"
50080 print:print "statistical results"
50090 print:print "effectivity of as/rs cart=",ea
50100 print "idle rate of as/rs cart=",ia
50110 for kn=1 to 6
50120 print "effectivity of machine center";kn;"=";em(kn)
50130 print "idle rate of machine center";kn;"=";im(kn)
50140 next kn
50150 print "average effectivity of machine center cell=";el
50160 print "average idle rate of machine center cell=";it
50180 print:for kn=1 to 8
50190 print "fetch rate of storage area";kn;"=";df(kn)
50200 next kn
50210 for kn=1 to 6
50215 print "route rate to machine center";kn;"=";dt(kn)
50220 next kn
50250 print:print "fetch rate for machine center cell=";ml
50260 print "fetch rate for turning cell=             ";m2
50262 for kn=1 to 6
50264 print "total number of outputs from m/c";kn;"is=";mo(kn)
50266 next kn
50270 print "total number of outputs from m/cs=       ";m3
50280 print "total number of ouputs from turning cell=";m4
50285 print "total number of dispatches=              ";n
50290 print:for kn=1 to 8
50300 print "current queues of storage area  ";kn;"=";lq(kn)
50310 next kn
50320 print "current queues of retrieval gate=         ";lq(30)
50350 print "current queues of turning cell=           ";lq(16)
50360 print:for kn=22 to 27
50370 print "current queues of machine center";kn-21;"=";lq(kn)
50380 next kn
50390 print:for kn=1 to 8
50395 if lq(kn)<1 then 50435
50398 print "current queue sequence of storage area";kn
```

```
50400 for nn=1 to lq(kn)
50420 print oq(kn,nn);
50430 next nn
50432 print
50435 next kn
50440 print:for kn=22 to 27
50445 if lq(kn)<1 then 50485
50448 print "current queue sequence of m/c center  ";kn-21
50450 for nn=1 to lq(kn)
50470 print oq(kn,nn);
50480 next nn
50482 print
50485 next kn
50490 if lq(16)<1 then 50530
50492 print:print "current queue sequence of turning cell"
50495 for kn=1 to lq(16)
50510 print oq(16,kn);
50520 next kn
50530 print:print "current queue sequence of retrieval queue"
50535 for kn=1 to lq(30)
50550 print oq(30,kn);
50560 next kn
50570 print:print "total fetch time of as/rs    ";sm/3600
50580 print:print "total processing time of m/c=";su/3600
50590 print:print "total throughput time(tp)=   ";tu
50600 print:print "total production lateness=   ";tl
50610 print:print "total idle time on machine centers=";td
50900 print#1,4:close1,4
50910 stop:end
51000 data 4.1184,190.38,52.5744
51050 data 7.1340,120.37,64.2060
51100 data 1.9817,92.32,33.3437
51150 data 0.9650,17.93,8.6849
51240 data 1.2407,107.86,26.6749
51290 data 13.820,231.81,124.380
51360 data 1.7404,26.93,15.6638
51362 data 0.2501,0.2155,0.2004,0.1886,0.1842,0.1761,0.1673,0.1637
51365 data 0.1357,0.1334,0.1453,0.1609,0.1759,0.1764
51370 data 0.1272,0.1249,0.1368,0.1524,0.1674,0.1679
51375 data 0.1205,0.1182,0.1301,0.1457,0.1607,0.1612
51380 data 0.1115,0.1092,0.1211,0.1367,0.1517,0.1523
51385 data 0.1028,0.1005,0.1124,0.1280,0.1430,0.1435
51390 data 0.0977,0.0955,0.1073,0.1229,0.1380,0.1385
51395 data 0.0911,0.0888,0.1007,0.1163,0.1314,0.1319
51400 data 0.0823,0.0800,0.0919,0.1075,0.1225,0.1230
51405 data 0.1786,0.1701,0.1634,0.1544,0.1457,0.1406,0.1340
51410 data 0.2017,0.2173,0.2275,0.2327,0.2427,0.2581,0.1229
51430 data 1,as,0,6.5261,0.9436
```

```
51440 data 2,as,0,13.0351,0.9486
51450 data 3,as,0,16.2764,0.9486
51460 data 4,as,0,33.3488,0.9486
51470 data 5,as,0,69.8439,0.9486
51480 data 6,as,0,80.2724,0.9486
51490 data 7,as,0,85.6907,0.9486
51500 data 8,mc,4,89.4743,17.3842
51510 data 9,as,0,97.7001,0.9486
51520 data 10,as,0,108.161,0.9486
51530 data 11,as,0,111.383,0.9486
51540 data 12,as,0,115.849,0.9486
51550 data 13,as,0,119.426,0.9486
51560 data 14,as,0,133.68,0.9486
51570 data 15,as,0,148.243,0.9486
51580 data 16,as,0,157.014,0.9486
51590 data 17,as,0,164.96,0.9486
51600 data 18,as,0,172.834,0.9486
51610 data 19,as,0,181.9,0.9486
51620 data 20,as,0,196.734,0.9486
51630 data 21,as,0,220.676,0.9486
51640 data 22,as,0,231.714,0.9486
51650 data 23,mc,2,245.996,29.9685
51660 data 24,as,0,248.269,0.9486
51670 data 25,as,0,266.28,0.9486
51680 data 26,as,0,279.653,0.9486
51690 data 27,as,0,287.488,0.9486
51700 data 28,as,0,305.805,0.9486
51710 data 29,mc,4,316.27,17.3842
51720 data 30,as,0,327.974,0.9486
51730 data 31,as,0,331.635,0.9486
51740 data 32,mc,5,336.984,45.6353
51750 data 33,as,0,337.934,0.9486
51760 data 34,as,0,380.326,0.9486
51770 data 35,mc,1,394.469,32.6846
51780 data 36,as,0,400.588,0.9486
51790 data 37,as,0,404.446,0.9486
51800 data 38,as,0,410.911,0.9486
51810 data 39,as,0,417.741,0.9486
51820 data 40,as,0,421.378,0.9486
51830 data 41,as,0,452.248,0.9486
51840 data 42,as,0,458.694,0.9486
51850 data 43,mc,1,460.889,32.6846
51860 data 44,as,0,463.981,0.9486
51870 data 45,mc,2,466.391,29.9685
51880 data 46,as,0,482.697,0.9486
51890 data 47,as,0,503.113,0.9486
51900 data 48,mc,6,504.049,45.6353
51910 data 49,as,0,513.047,0.9486
```

```
 51920 data 50,mc,3,514.402,102.5036
 51930 data 51,as,0,521.64,0.9486
 51940 data 52,as,0,549.064,0.9486
 51950 data 53,as,0,552.099,0.9486
 51960 data 54,as,0,555.33,0.9486
 51970 data 55,as,0,563.281,0.9486
 51980 data 56,as,0,577.802,0.9486
 51990 data 57,as,0,590.974,0.9486
 52000 data 58,as,0,601.758,0.9486
 52010 data 59,as,0,609.993,0.9486
 52020 data 60,as,0,624.369,0.9486
 52030 data 61,as,0,631.069,0.9486
 52040 data 62,as,0,639.408,0.9486
 52050 data 63,as,0,644.841,0.9486
 52060 data 64,as,0,652.657,0.9486
 52070 data 65,mc,5,662.231,45.6353
 52080 data 66,as,0,667.277,0.9486
 52090 data 67,as,0,676.122,0.9486
 52100 data 68,as,0,679.932,0.9486
 52110 data 69,as,0,693.424,0.9486
 52120 data 70,as,0,718.626,0.9486
ready.
```

```
2 open2,4,6:print#2,chr$(23)
5 open1,4:cmd1
10 print "3"
20 print "*************************************************************"
30 print "*                 physical simulation for fms               *"
40 print "*                    (slack-ninq)-(twk)                     *"
50 print "*************************************************************"
100 dim d(30),lq(30),oq(30,5),dx(30),xx(30),pn(30,5),tp(77),sl(77)
110 dim tf(77),w3(8,16),rl(77),x(77),y(77),tl(77),tr(77),id(77)
120 dim sk(77),at(77),la(77),cp(6,6),bo(70),bf(70),du(70),mn(70),t$(70)
125 dim lc(77)
130 dra=59471:poke 59459,127
150 poke 59467, peek(59467) and 227
160 poke 59468, peek(59468) and 31 or 224
170 for i=1 to 30:d(i)=-1:lq(i)=0:dx(i)=0:xx(i)=0:next i
210 for i=1 to 30:for j=1 to 5:oq(i,j)=0:next j:next i
220 for i=1 to 30:for j=1 to 5:pn(i,j)=0:next j:next i
230 for i=1 to 77:rl(i)=0:x(i)=0:y(i)=0:sl(i)=0:sk(i)=0:tr(i)=0:next i
240 for i=1 to 77:at(i)=0:la(i)=0:tp(i)=0:tl(i)=0:lc(i)=0:id(i)=0:next i
245 for i=1 to 6:mo(i)=0:dt(i)=0:rt(i)=0:rr(i)=0:pp(i)=0:next i
258 for i=1 to 70:bo(i)=0:bf(i)=0:du(i)=0:next i
260 for i=1 to 7:pt(i)=0:vl(i)=0:w6(i)=0:next i
275 for i=1 to 8:df(i)=0:next i
278 for i=1 to 8:for j=1 to 16:w3(i,j)=0:next j:next i
290 t=0:f=0:tt=0:ff=0
300 n=0:mm=0:m1=0:m2=0:m3=0:m4=0:tu=0:t1=0:td=0
310 ta=0:w1=0:w4=0.05:w5=0.07:ms=0:t3=0:t5=0:t6=0:t7=0:t8=0
330 for i=1 to 7:lq(i)=5:next i
340 for i=8 to 30:lq(i)=0:next i
350 j=1
360 for i=j to 7:oq(i,j)=i+(i-j+1)*10:next i
370 j=j+1
380 if j<=5 then 360
390 j=5:jj=j-1
400 for i=jj to 1 step -1
410 oq(i,j)=jj+70-11*(jj-i)
420 next i
430 j=j-1:jj=j-1
440 if j>=2 then goto 400
441 for i=1 to 7:for j=1 to 5
442 pn(i,j)=int(oq(i,j)/11+0.6)
443 next j:next i
445 for i=1 to 77:tf(i)=999999999999:next i
450 for i=1 to 7
460 read pt(i),vl(i),al(i)
470 pt(i)=pt(i)*3600:al(i)=al(i)*3600
480 next i
490 for i=1 to 8:read w6(i):next i
```

```
492 for i=1 to 8:for j=1 to 6
494 read w3(i,j)
496 next j:next i
498 for i=1 to 7:read w3(i,16):next i
499 for i=1 to 7:read ro(i):next i
500 print "do you wish to change the status of any output?"
510 print "enter 1 for yes, 2 for no": input x
520 if x<>1 then 580
530 print "enter desired output number": input g
540 if g<32 then 560
550 print "illegal output number (must be 0-31)":goto 530
560 poke dra,g:poke dra,0:goto 500
580 print "3":print "enter simulation run time in minutes."
590 input sr:sr=sr*3600:print "initialization has been completed."
620 ti$="000000":ss=ti
630 print "simulation starting time is ",ss/3600
650 for i=1 to 70
660 read i,t$(i),mn(i),bo(i),du(i)
670 bo(i)=bo(i)*3600+ss:du(i)=du(i)*3600:bf(i)=bo(i)+du(i):next i
700 gosub 30000
720 gosub 11000
730 gosub 13000
750 gosub 40000
760 gosub 45000
770 gosub 41000
780 goto 700
10000 tm=ti:return
11000 if lq(8)>0 then 11040
11005 for j=1 to 7
11010 if lq(j)<1 then 11025
11012 pn(j,1)=int(oq(j,1)/11+0.6)
11025 next j
11028 qq=0
11030 for j=1 to 7:if lq(j)<1 then qq=qq+1:next j
11032 if qq=7 then 11036
11034 goto 11039
11036 gosub 40000:gosub 30000:goto 11000
11039 gosub 17000:goto 11100
11040 f=8:goto 11130
11100 if oq(f,1)>10 and oq(f,1)<20 then 11160
11110 if oq(f,1)>30 and oq(f,1)<40 then 11160
11120 if oq(f,1)>50 and oq(f,1)<60 then 11160
11130 pq=0
11135 for k=22 to 27:if lq(k)>4 then pq=pq+1:next k
11140 if pq=6 then 11157
11145 gosub 17500
11152 kl=t-21:goto 11170
11157 gosub 40000:goto 11000
```

```
11160 if lq(16)>4 then 11164
11162 kl=16:goto 11170
11164 gosub 45000:goto 11000
11170 gosub 12000:return
12000 gosub 10000
12006 if tm/3600<=(ti/3600)-wl then 12010
12008 gosub 40000:goto 12006
12010 wl=0:tl(oq(f,1))=ti
12015 print "current time=";ti/3600
12020 poke dra,28:poke dra,0
12040 poke dra,f+50
12050 if peek(dra)=f+50 then 12070
12060 goto 12040
12070 poke dra,28:poke dra,0
12072 gosub 10000
12074 if tm/3600>(ti/3600)-w3(f,kl) then 12074
12080 poke dra,f:poke dra,0
12090 t5=ti:print "loading part  ";oq(f,1);"from storage";f:t6=ti-t5
12095 gosub 10000
12100 if tm/3600>(ti/3600)-w4 then 12100
12102 poke dra,f:poke dra,0
12104 gosub 10000
12106 if tm/3600>(ti/3600)-w5 then 12106
12110 poke dra,28:poke dra,0
12130 t7=ti:print "returning with";oq(f,1);"from storage";f:t8=ti-t7
12140 poke dra,50
12150 if peek(dra)=178 then 12170
12160 goto 12140
12170 poke dra,28:poke dra,0:xa=ti
12180 ta=ti-tl(oq(f,1))-(wl+w3(f,kl)+w4+w5)*3600-t6-t8
12185 n=n+1:ta=ta/3600
12190 print "fetch time is ";ta
12200 ft=(ta+w3(f,kl)+w4+w5)*3600
12210 sm=sm+ft
12220 return
13000 if f=8 then 13040
13010 if oq(f,1)>10 and oq(f,1)<20 then 13500
13020 if oq(f,1)>30 and oq(f,1)<40 then 13500
13030 if oq(f,1)>50 and oq(f,1)<60 then 13500
13040 if d(16)=1 then 13070
13050 poke dra,16:poke dra,0:d(16)=d(16)*(-1)
13070 print "part";oq(f,1);"should be routed to machine center";t
13090 if t=27 then 13130
13100 if d(t-5)=1 then 13120
13110 poke dra,t-5:poke dra,0:d(t-5)=d(t-5)*(-1)
13120 if t=22 then 13170
13130 for a=t-6 to 17 step -1
13140 if d(a)=-1 then 13160
```

```
13150 poke dra,a:poke dra,0:d(a)=d(a)*(-1)
13160 next a
13170 poke dra,t+10
13180 if peek(dra)=t+10 then 13170
13190 tr(oq(f,1))=xa/3600+ro(t-21)
13200 gosub 14000
13210 gosub 16000
13220 m1=m1+1:df(f)=df(f)+1:dt(t-21)=dt(t-21)+1:return
13500 if d(16)=-1 then 13520
13510 poke dra,16:poke dra,0:d(16)=d(16)*(-1)
13520 print "part";oq(f,1);"should goto turning cell"
13530 poke dra,40:if peek(dra)=40 then 13530
13540 t=16:tr(oq(f,1))=xa/3600+ro(7)
13542 gosub 14000
13545 gosub 16000
13550 m2=m2+1:df(f)=df(f)+1:return
14000 for tt=22 to 27
14010 if lq(tt)>0 and d(tt)=-1 then 14040
14020 next tt
14030 return
14040 gosub 20100:goto 14020
16000 lq(t)=lq(t)+1:oq(t,lq(t))=oq(f,1)
16010 if lq(f)<1 then return
16020 lq(f)=lq(f)-1
16030 for j=1 to lq(f):oq(f,j)=oq(f,j+1):next j
16040 return
17000 xc=ti:for j=1 to 7
17020 if lq(j)<1 then 17080
17030 if pn(j,1)=1 or pn(j,1)=3 or pn(j,1)=5 then 17035
17032 et=0:goto 17040
17035 et=1.7243*3600
17040 if df(j)>=5 then 17070
17050 sl(oq(j,1))=al(pn(j,1))-pt(pn(j,1))+at(oq(j,1))*3600-et-xc
17055 sl(oq(j,1))=sl(oq(j,1))/3600
17060 x(oq(j,1))=1:y(oq(j,1))=0:goto 17080
17070 x(oq(j,1))=0:y(oq(j,1))=1:sk(oq(j,1))=lc(oq(j,1))-xc/3600
17080 next j
17090 f=1
17100 if lq(f)<1 then 17220
17110 f1=f+1
17120 if f1>7 then return
17130 if lq(f1)<1 then 17170
17140 xf=x(oq(f,1))*sl(oq(f,1))+y(oq(f,1))*sk(oq(f,1))
17150 yf=x(oq(f1,1))*sl(oq(f1,1))+y(oq(f1,1))*sk(oq(f1,1))
17160 if xf>yf then 17210
17170 f1=f1+1
17180 if f1>7 then return
17200 goto 17130
```

```
17210 f=f1:goto 17170
17220 f=f+1
17230 if f>7 then 17090
17240 goto 17100
17500 t=22
17510 if lq(t)>4 then 17600
17520 th=t+1
17530 if th>27 then return
17540 if lq(th)>4 then 17560
17550 if lq(t)>lq(th) then 17590
17560 th=th+1
17570 if th>27 then return
17580 goto 17540
17590 t=th:goto 17560
17600 t=t+1
17610 if t>27 then 17500
17620 goto 17510
18000 nc=tn-21
18035 pn(tn,1)=int(oq(tn,1)/11+0.6)
18040 pp(nc)=pt(pn(tn,1))
18050 rt(nc)=rr(nc)+pp(nc):rr(nc)=rt(nc)
18060 rt(nc)=rt(nc)/3600
18070 print "total processing time of m/c";tn;"is";rt(nc)
18080 su=su+pp(nc)
18090 ms=(sm+su/6)/(2*sr):t3=ti/3600
18100 print "current time","system effectivity"
18110 print t3,ms
18120 for j=1 to lq(tn):cp(nc,j)=0:next j
18130 if lq(tn)<2 then 18175
18140 for j=2 to lq(tn)
18150 pn(tn,j)=int(oq(tn,j)/11+0.6)
18160 cp(nc,j+1)=cp(nc,j)+pt(pn(tn,j)):next j
18165 cp(nc,lq(tn)+1)=cp(nc,lq(tn)+1)/3600
18170 print "remaining time of m/c queue";tn;"is";cp(nc,lq(tn)+1)
18175 if lq(tn)<1 then 18230
18180 lq(tn)=lq(tn)-1
18190 if lq(tn)<1 then 18230
18200 for j=1 to lq(tn)
18210 oq(tn,j)=oq(tn,j+1)
18220 next j
18230 return
20100 if dx(tt)=1 then return
20110 poke dra,tt:poke dra,0:d(tt)=d(tt)*(-1)
20112 id(oq(tt,1))=ti/3600-tr(oq(tt,1))
20115 print "waiting time of part";oq(tt,1);"on m/c";tt;"is";id(oq(tt,1))
20120 td=td+id(oq(tt,1))
20125 pn(tt,1)=int(oq(tt,1)/11+0.6)
20130 if dx(tt)=2 then return
```

```
20135 gosub 10000
20150 tf(oq(tt,1))=pt(pn(tt,1))+tm
20220 return
30000 if lq(30)<2 then return
30010 if rl(oq(30,1))=2 then 30025
30020 gosub 35000:goto 30030
30025 ff=8
30030 print "part";oq(30,1);"should return to storage";ff
30040 poke dra,60
30050 if peek(dra)<>188 then 30040
30060 if d(30)=1 then 30100
30070 poke dra,30:poke dra,0:d(30)=d(30)*(-1)
30080 gosub 10000
30090 if tm/3600>(ti/3600)-0.03 then 30090
30100 poke dra,30:poke dra,0:d(30)=d(30)*(-1)
30105 xb=ti:tp(oq(30,1))=xb-at(oq(30,1))*3600
30110 poke dra,60
30120 if peek(dra)=60 then 30110
30125 if ff=1 then 30160
30130 if d(ff+7)=1 then 30150
30140 poke dra,ff+7:poke dra,0:d(ff+7)=d(ff+7)*(-1)
30150 if ff=8 then 30295
30160 for l=ff+8 to 15
30170 if d(l)=-1 then 30190
30180 poke dra,l:poke dra,0:d(l)=d(l)*(-1)
30190 next l
30192 la(oq(30,1))=tp(oq(30,1))-al(pn(30,1))
30194 tp(oq(30,1))=tp(oq(30,1))/3600:la(oq(30,1))=la(oq(30,1))/3600
30196 print "throughput time of part    ";oq(30,1);"is=";tp(oq(30,1))
30198 print "production lateness of part";oq(30,1);"is=";la(oq(30,1))
30199 tu=tu+tp(oq(30,1)):tl=tl+la(oq(30,1))
30200 at(oq(30,1))=xb+w6(ff)*3600
30205 if pn(30,1)=2 or pn(30,1)=4 or pn(30,1)=6 or pn(30,1)=7 then 30210
30208 lc(oq(30,1))=al(pn(30,1))+at(oq(30,1))-pt(pn(30,1))-(1.7243*3600)
30209 goto 30220
30210 lc(oq(30,1))=al(pn(30,1))+at(oq(30,1))-pt(pn(30,1))
30220 lc(oq(30,1))=lc(oq(30,1))/3600:at(oq(30,1))=at(oq(30,1))/3600
30230 print "arrival time of a new part ";oq(30,1);"is=";at(oq(30,1))
30295 lq(ff)=lq(ff)+1:oq(ff,lq(ff))=oq(30,1)
30300 if lq(30)<1 then return
30305 lq(30)=lq(30)-1
30308 if lq(30)<1 then return
30310 for j=1 to lq(30)
30320 oq(30,j)=oq(30,j+1)
30330 next j:return
35000 ff=oq(30,1)-(int(oq(30,1)/11+0.6))*10
35010 pn(30,1)=int(oq(30,1)/11+0.6):return
40000 if ti>=(sr+ss) then 50000
```

```
40010 for tn=22 to 27
40020 if d(tn)=-1 then 40060
40030 if lq(tn)<1 then 40060
40040 if lq(30)>4 then 40070
40050 if ti>=tf(oq(tn,1)) then 40500
40060 next tn
40070 return
40500 print "part";oq(tn,1);"is done at location";tn
40510 if dx(tn)=2 and xx(tn)<=tf(oq(tn,1)) then 40514
40512 goto 40520
40514 dx(tn)=10
40520 poke dra,tn:poke dra,0:d(tn)=d(tn)*(-1):mo(tn-21)=mo(tn-21)+1
40550 lq(30)=lq(30)+1
40560 oq(30,lq(30))=oq(tn,1)
40570 rl(oq(30,lq(30)))=1
40575 gosub 18000
40580 m3=m3+1:goto 40060
41000 for ic=1 to 70
41150 if ti>=bo(ic) then 41200
41160 if mn(ic)=0 then 41180
41170 if ti>=bf(ic) then 41400
41180 next ic:return
41200 if t$(ic)="as" then 41610
41220 tj=mn(ic)+21:pn(tj,1)=int(oq(tj,1)/11+0.6)
41230 if d(tj)=-1 then 41255
41240 bo(ic)=tf(oq(tj,1)):bf(ic)=bo(ic)+du(ic)
41250 if bo(ic)<ti then return
41255 dx(tj)=1
41260 print "machine center";tj;"fails at";bo(ic)/3600
41270 bo(ic)=bo(ic)+999999999999:return
41400 tj=mn(ic)+21:pn(tj,1)=int(oq(tj,1)/11+0.6)
41440 print "failed machine center";tj;"is repaired at";bf(ic)/3600
41442 if lq(tj)<1 then 41460
41450 tf(oq(tj,1))=bf(ic)+pt(pn(tj,1)):xx(tj)=tf(oq(tj,1))
41460 dx(tj)=2:bf(ic)=bf(ic)+999999999999:return
41610 print "as/rs cart fails. failure number is";ic
41620 wl=du(ic)/3600:bo(ic)=bo(ic)+999999999999:return
45000 if lq(30)>4 then return
45010 poke dra,59
45020 if peek(dra)=59 then 45040
45030 return
45040 m4=m4+1:tn=29
45050 lq(tn)=lq(tn)+1:oq(tn,lq(tn))=oq(16,1)
45060 print "part";oq(tn,1);"is done at location";tn
45070 poke dra,tn:poke dra,0:d(tn)=d(tn)*(-1)
45080 gosub 10000
45090 if tm/3600>(ti/3600)-0.04 then 45090
45100 poke dra,tn:poke dra,0:d(tn)=d(tn)*(-1)
```

```
45110 if lq(16)<1 then 45150
45120 lq(16)=lq(16)-1
45130 if lq(16)<1 then 45150
45140 for j=1 to lq(16):oq(16,j)=oq(16,j+1):next j
45150 if lq(tn)<1 then 45190
45160 lq(tn)=lq(tn)-1
45170 if lq(tn)<1 then 45190
45180 for j=1 to lq(tn):oq(tn,j)=oq(tn,j+1):next j
45190 lq(30)=lq(30)+1
45200 oq(30,lq(30))=oq(tn,1)
45210 rl(oq(30,lq(30)))=2
45220 return
50000 ea=sm/sr:ia=1-ea
50005 for kn=1 to 6:em(kn)=rt(kn)*3600/sr:next kn
50010 for kn=1 to 6:im(kn)=1-em(kn):next kn
50040 el=(em(1)+em(2)+em(3)+em(4)+em(5)+em(6))/6:it=1-el
50050 for kn=1 to 8:df(kn)=df(kn)/n:next kn
50060 ml=ml/n:m2=m2/n
50070 print "3"
50080 print:print "statistical results"
50090 print:print "effectivity of as/rs cart=",ea
50100 print "idle rate of as/rs cart=",ia
50110 for kn=1 to 6
50120 print "effectivity of machine center";kn;"=";em(kn)
50130 print "idle rate of machine center";kn;"=";im(kn)
50140 next kn
50150 print "average effectivity of machine center cell=";el
50160 print "average idle rate of machine center cell=";it
50180 print:for kn=1 to 8
50190 print "fetch rate of storage area";kn;"=";df(kn)
50200 next kn
50210 for kn=1 to 6
50215 print "route rate to machine center";kn;"=";dt(kn)
50220 next kn
50250 print:print "fetch rate for machine center cell=";ml
50260 print "fetch rate for turning cell=          ";m2
50262 for kn=1 to 6
50264 print "total number of outputs from m/c";kn;"is=";mo(kn)
50266 next kn
50270 print "total number of outputs from m/cs=       ";m3
50280 print "total number of ouputs from turning cell=";m4
50285 print "total number of dispatches=              ";n
50290 print:for kn=1 to 8
50300 print "current queues of storage area  ";kn;"=";lq(kn)
50310 next kn
50320 print "current queues of retrieval gate=         ";lq(30)
50350 print "current queues of turning cell=           ";lq(16)
50360 print:for kn=22 to 27
```

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50370 print "current queues of machine center";kn-21;"=";lq(kn)
50380 next kn
50390 print:for kn=1 to 8
50395 if lq(kn)<1 then 50435
50398 print "current queue sequence of storage area";kn
50400 for nn=1 to lq(kn)
50420 print oq(kn,nn);
50430 next nn
50432 print
50435 next kn
50440 print:for kn=22 to 27
50445 if lq(kn)<1 then 50485
50448 print "current queue sequence of m/c center";kn-21
50450 for nn=1 to lq(kn)
50470 print oq(kn,nn);
50480 next nn
50482 print
50485 next kn
50490 if lq(16)<1 then 50530
50492 print:print "current queue sequence of turning cell"
50495 for kn=1 to lq(16)
50510 print oq(16,kn);
50520 next kn
50530 print:print "current queue sequence of retrieval queue"
50535 for kn=1 to lq(30)
50550 print oq(30,kn);
50560 next kn
50570 print:print "total fetch time of as/rs=   ";sm/3600
50580 print:print "total processing time of m/c=";su/3600
50590 print:print "total throughput time(tp)=   ";tu
50600 print:print "total production lateness=   ";tl
50610 print:print "total idle time on machine centers=";td
50900 print#1,4:close1,4
50910 stop:end
51000 data 4.1210,190.38,52.6080
51050 data 7.1386,120.37,64.2469
51100 data 1.9829,92.32,33.3649
51150 data 0.9656,17.93,8.6904
51240 data 1.2415,107.86,26.6920
51290 data 13.8288,231.81,124.4590
51360 data 1.7415,26.93,15.6738
51362 data 0.2501,0.2155,0.2004,0.1886,0.1842,0.1761,0.1673,0.1637
51365 data 0.1356,0.1333,0.1452,0.1609,0.1759,0.1764
51370 data 0.1271,0.1249,0.1368,0.1524,0.1674,0.1680
51375 data 0.1204,0.1182,0.1301,0.1457,0.1607,0.1613
51380 data 0.1115,0.1092,0.1211,0.1367,0.1518,0.1523
51385 data 0.1027,0.1005,0.1124,0.1280,0.1430,0.1435
51390 data 0.0977,0.0954,0.1073,0.1230,0.1380,0.1385
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51395 data 0.0911,0.0888,0.1007,0.1164,0.1314,0.1319
51400 data 0.0823,0.0800,0.0919,0.1075,0.1225,0.1231
51405 data 0.1785,0.1700,0.1633,0.1544,0.1456,0.1406,0.1340
51410 data 0.2017,0.2173,0.2275,0.2327,0.2427,0.2581,0.1229
51430 data 1,as,0,6.5302,0.9492
51440 data 2,as,0,13.0434,0.9492
51450 data 3,as,0,16.2867,0.9492
51460 data 4,as,0,33.3701,0.9492
51470 data 5,as,0,69.8884,0.9492
51480 data 6,as,0,80.3237,0.9492
51490 data 7,as,0,85.7453,0.9492
51500 data 8,mc,4,89.5313,17.3953
51510 data 9,as,0,97.7624,0.9492
51520 data 10,as,0,108.23,0.9492
51530 data 11,as,0,111.454,0.9492
51540 data 12,as,0,115.923,0.9492
51550 data 13,as,0,119.502,0.9492
51560 data 14,as,0,133.765,0.9492
51570 data 15,as,0,148.337,0.9492
51580 data 16,as,0,157.114,0.9492
51590 data 17,as,0,165.065,0.9492
51600 data 18,as,0,172.944,0.9492
51610 data 19,as,0,182.016,0.9492
51620 data 20,as,0,196.859,0.9492
51630 data 21,as,0,220.816,0.9492
51640 data 22,as,0,231.862,0.9492
51650 data 23,mc,2,246.153,29.9876
51660 data 24,as,0,248.427,0.9492
51670 data 25,as,0,266.449,0.9492
51680 data 26,as,0,279.832,0.9492
51690 data 27,as,0,287.672,0.9492
51700 data 28,as,0,306.001,0.9492
51710 data 29,mc,4,316.472,17.3953
51720 data 30,as,0,328.183,0.9492
51730 data 31,as,0,331.846,0.9492
51740 data 32,mc,5,337.199,45.6645
51750 data 33,as,0,338.15,0.9492
51760 data 34,as,0,380.568,0.9492
51770 data 35,mc,1,394.721,32.7054
51780 data 36,as,0,400.844,0.9492
51790 data 37,as,0,404.704,0.9492
51800 data 38,as,0,411.174,0.9492
51810 data 39,as,0,418.008,0.9492
51820 data 40,as,0,421.646,0.9492
51830 data 41,as,0,452.537,0.9492
51840 data 42,as,0,458.987,0.9492
51850 data 43,mc,1,461.183,32.7054
51860 data 44,as,0,464.277,0.9492
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```
51870 data 45,mc,2,466.689,29.9876
51880 data 46,as,0,483.005,0.9492
51890 data 47,as,0,503.434,0.9492
51900 data 48,mc,6,504.37,45.6645
51910 data 49,as,0,513.374,0.9492
51920 data 50,mc,3,514.731,102.569
51930 data 51,as,0,521.972,0.9492
51940 data 52,as,0,549.415,0.9492
51950 data 53,as,0,552.451,0.9492
51960 data 54,as,0,555.684,0.9492
51970 data 55,as,0,563.64,0.9492
51980 data 56,as,0,578.171,0.9492
51990 data 57,as,0,591.351,0.9492
52000 data 58,as,0,602.142,0.9492
52010 data 59,as,0,610.382,0.9492
52020 data 60,as,0,624.768,0.9492
52030 data 61,as,0,631.472,0.9492
52040 data 62,as,0,639.815,0.9492
52050 data 63,as,0,645.252,0.9492
52060 data 64,as,0,653.074,0.9492
52070 data 65,mc,5,662.654,45.6645
52080 data 66,as,0,667.702,0.9492
52090 data 67,as,0,676.553,0.9492
52100 data 68,as,0,680.366,0.9492
52110 data 69,as,0,693.867,0.9492
52120 data 70,as,0,719.084,0.9492
ready.
```

```
2 open2,4,6:print#2,chr$(22)
5 open1,4:cmd1
10 print "3"
20 print "***************************************************************"
30 print "*                  physical simulation for fms                  *"
40 print "*                     (s/pt-wing)-(twk)                         *"
50 print "***************************************************************"
100 dim d(30),lq(30),oq(30,5),dx(30),xx(30),pn(30,5),tp(77),sl(77)
110 dim tf(77),w3(8,16),rl(77),x(77),y(77),tl(77),tr(77),id(77),bo(70)
120 dim sk(77),at(77),la(77),cp(6,6),bf(70),du(70),mn(70),t$(70)
125 dim lc(77)
130 dra=59471:poke 59459,127
150 poke 59467, peek(59467) and 227
160 poke 59468, peek(59468) and 31 or 224
170 for i=1 to 30:d(i)=-1:lq(i)=0:dx(i)=0:xx(i)=0:next i
210 for i=1 to 30:for j=1 to 5:oq(i,j)=0:next j:next i
220 for i=1 to 30:for j=1 to 5:pn(i,j)=0:next j:next i
230 for i=1 to 77:rl(i)=0:x(i)=0:y(i)=0:sl(i)=0:sk(i)=0:tr(i)=0:next i
240 for i=1 to 77:at(i)=0:la(i)=0:tp(i)=0:tl(i)=0:lc(i)=0:id(i)=0:next i
245 for i=1 to 6:mo(i)=0:dt(i)=0:rt(i)=0:rr(i)=0:pp(i)=0:next i
258 for i=1 to 70:bo(i)=0:bf(i)=0:du(i)=0:next i
260 for i=1 to 7:pt(i)=0:vl(i)=0:mp(i)=0:w6(i)=0:next i
275 for i=1 to 8:df(i)=0:next i
278 for i=1 to 8:for j=1 to 16:w3(i,j)=0:next j:next i
290 t=0:f=0:tt=0:ff=0
300 n=0:sm=0:ml=0:m2=0:m3=0:m4=0:tu=0:tl=0:td=0
310 ta=0:wl=0:w4=0.05:w5=0.07:ms=0:t3=0:t5=0:t6=0:t7=0:t8=0
330 for i=1 to 7:lq(i)=5:next i
340 for i=8 to 30:lq(i)=0:next i
350 j=1
360 for i=j to 7:oq(i,j)=i+(i-j+1)*10:next i
370 j=j+1
380 if j<=5 then 360
390 j=5:jj=j-1
400 for i=jj to 1 step -1
410 oq(i,j)=jj+70-11*(jj-i)
420 next i
430 j=j-1:jj=j-1
440 if j>=2 then goto 400
441 for i=1 to 7:for j=1 to 5
442 pn(i,j)=int(oq(i,j)/11+0.6)
443 next j:next i
445 for i=1 to 77:tf(i)=999999999999:next i
450 for i=1 to 7
460 read pt(i),vl(i),al(i)
470 pt(i)=pt(i)*3600:al(i)=al(i)*3600
480 next i
490 for i=1 to 8:read w6(i):next i
```

```
492 for i=1 to 8:for j=1 to 6
494 read w3(i,j)
496 next j:next i
498 for i=1 to 7:read w3(i,16):next i
499 for i=1 to 7:read ro(i):next i
500 print "do you wish to change the status of any output?"
510 print "enter 1 for yes, 2 for no": input x
520 if x<>1 then 580
530 print "enter desired output number": input g
540 if g<32 then 560
550 print "illegal output number (must be 0-31)":goto 530
560 poke dra,g:poke dra,0:goto 500
580 print "3":print "enter simulation run time in minutes."
590 input sr:sr=sr*3600:print "initialization has been completed."
620 ti$="000000":ss=ti
630 print "simulation starting time is ",ss/3600
650 for i=1 to 70
660 read i,t$(i),mn(i),bo(i),du(i)
670 bo(i)=bo(i)*3600+ss:du(i)=du(i)*3600:bf(i)=bo(i)+du(i):next i
700 gosub 30000
710 gosub 18500
720 gosub 11000
730 gosub 13000
750 gosub 40000
760 gosub 45000
770 gosub 41000
780 goto 700
10000 tm=ti:return
11000 if lq(8)>0 then 11040
11005 for j=1 to 7
11010 if lq(j)<1 then 11025
11012 pn(j,1)=int(oq(j,1)/11+0.6)
11015 if pn(j,1)=2 or pn(j,1)=4 or pn(j,1)=6 or pn(j,1)=7 then 11020
11018 mp(pn(j,1))=pt(pn(j,1))/3600+1.7427:goto 11025
11020 mp(pn(j,1))=pt(pn(j,1))/3600
11025 next j
11028 qq=0
11030 for j=1 to 7:if lq(j)<1 then qq=qq+1:next j
11032 if qq=7 then 11036
11034 goto 11039
11036 gosub 40000:gosub 30000:goto 11000
11039 gosub 17000:goto 11100
11040 f=8:goto 11130
11100 if oq(f,1)>10 and oq(f,1)<20 then 11160
11110 if oq(f,1)>30 and oq(f,1)<40 then 11160
11120 if oq(f,1)>50 and oq(f,1)<60 then 11160
11130 pq=0
11135 for k=22 to 27:if lq(k)>4 then pq=pq+1:next k
```

```
11140 if pq=6 then 11157
11145 gosub 17500
11152 kl=t-21:goto 11170
11157 gosub 40000:goto 11000
11160 if lq(16)>4 then 11164
11162 kl=16:goto 11170
11164 gosub 45000:goto 11000
11170 gosub 12000:return
12000 gosub 10000
12006 if tm/3600<=(ti/3600)-wl then 12010
12008 gosub 40000:goto 12006
12010 wl=0:tl(oq(f,l))=ti
12015 print "current time=";ti/3600
12020 poke dra,28:poke dra,0
12040 poke dra,f+50
12050 if peek(dra)=f+50 then 12070
12060 goto 12040
12070 poke dra,28:poke dra,0
12072 gosub 10000
12074 if tm/3600>(ti/3600)-w3(f,kl) then 12074
12080 poke dra,f:poke dra,0
12090 t5=ti:print "loading part  ";oq(f,l);"from storage";f:t6=ti-t5
12095 gosub 10000
12100 if tm/3600>(ti/3600)-w4 then 12100
12102 poke dra,f:poke dra,0
12104 gosub 10000
12106 if tm/3600>(ti/3600)-w5 then 12106
12110 poke dra,28:poke dra,0
12130 t7=ti:print "returning with";oq(f,l);"from storage";f:t8=ti-t7
12140 poke dra,50
12150 if peek(dra)=178 then 12170
12160 goto 12140
12170 poke dra,28:poke dra,0:xa=ti
12180 ta=ti-tl(oq(f,l))-(wl+w3(f,kl)+w4+w5)*3600-t6-t8
12185 n=n+1:ta=ta/3600
12190 print "fetch time is ";ta
12200 ft=(ta+w3(f,kl)+w4+w5)*3600
12210 sm=sm+ft
12220 return
13000 if f=8 then 13040
13010 if oq(f,l)>10 and oq(f,l)<20 then 13500
13020 if oq(f,l)>30 and oq(f,l)<40 then 13500
13030 if oq(f,l)>50 and oq(f,l)<60 then 13500
13040 if d(16)=1 then 13070
13050 poke dra,16:poke dra,0:d(16)=d(16)*(-1)
13070 print "part";oq(f,l);"should be routed to machine center";t
13090 if t=27 then 13130
13100 if d(t-5)=1 then 13120
```

```
13110 poke dra,t-5:poke dra,0:d(t-5)=d(t-5)*(-1)
13120 if t=22 then 13170
13130 for a=t-6 to 17 step -1
13140 if d(a)=-1 then 13160
13150 poke dra,a:poke dra,0:d(a)=d(a)*(-1)
13160 next a
13170 poke dra,t+10
13180 if peek(dra)=t+10 then 13170
13190 tr(oq(f,1))=xa/3600+ro(t-21)
13200 gosub 14000
13210 gosub 16000
13220 ml=ml+1:df(f)=df(f)+1:dt(t-21)=dt(t-21)+1:return
13500 if d(16)=-1 then 13520
13510 poke dra,16:poke dra,0:d(16)=d(16)*(-1)
13520 print "part";oq(f,1);"should goto turning cell"
13530 poke dra,40:if peek(dra)=40 then 13530
13540 t=16:tr(oq(f,1))=xa/3600+ro(7)
13542 gosub 14000
13545 gosub 16000
13550 m2=m2+1:df(f)=df(f)+1:return
14000 for tt=22 to 27
14010 if lq(tt)>0 and d(tt)=-1 then 14040
14020 next tt
14030 return
14040 gosub 20100:goto 14020
16000 lq(t)=lq(t)+1:oq(t,lq(t))=oq(f,1)
16010 if lq(f)<1 then return
16020 lq(f)=lq(f)-1
16030 for j=1 to lq(f):oq(f,j)=oq(f,j+1):next j
16040 return
17000 xc=ti:for j=1 to 7
17020 if lq(j)<1 then 17080
17030 if pn(j,1)=1 or pn(j,1)=3 or pn(j,1)=5 then 17035
17032 et=0:goto 17040
17035 et=1.7427*3600
17040 if df(j)>=5 then 17070
17050 sl(oq(j,1))=al(pn(j,1))-pt(pn(j,1))+at(oq(j,1))*3600-et-xc
17055 sl(oq(j,1))=sl(oq(j,1))/3600
17060 x(oq(j,1))=1:y(oq(j,1))=0:goto 17080
17070 x(oq(j,1))=0:y(oq(j,1))=1:sk(oq(j,1))=lc(oq(j,1))-xc/3600
17080 next j
17090 f=1
17100 if lq(f)<1 then 17220
17110 f1=f+1
17120 if f1>7 then return
17130 if lq(f1)<1 then 17170
17140 xf=(x(oq(f,1))*sl(oq(f,1))+y(oq(f,1))*sk(oq(f,1)))/mp(pn(f,1))
17150 yf=(x(oq(f1,1))*sl(oq(f1,1))+y(oq(f1,1))*sk(oq(f1,1)))/mp(pn(f1,1))
```

```
17160 if xf>yf then 17210
17170 f1=f1+1
17180 if f1>7 then return
17200 goto 17130
17210 f=f1:goto 17170
17220 f=f+1
17230 if f>7 then 17090
17240 goto 17100
17500 for j=22 to 27
17510 if lq(j)>4 then cp(j-21,lq(j)+1)=999999999999
17520 next j
17530 t=22
17540 th=t+1
17550 if cp(t-21,lq(t)+1)>cp(th-21,lq(th)+1) then 17590
17560 th=th+1
17570 if th<=27 then 17550
17580 return
17590 t=th:goto 17560
18000 nc=tn-21
18035 pn(tn,1)=int(oq(tn,1)/11+0.6)
18040 pp(nc)=pt(pn(tn,1))
18050 rt(nc)=rr(nc)+pp(nc):rr(nc)=rt(nc)
18060 rt(nc)=rt(nc)/3600
18070 print "total processing time of m/c";tn;"is";rt(nc)
18080 su=su+pp(nc)
18090 ms=(ms+su/6)/(2*sr):t3=ti/3600
18100 print "current time","system effectivity"
18110 print t3,ms
18120 if lq(tn)<1 then 18180
18130 lq(tn)=lq(tn)-1
18140 if lq(tn)<1 then 18180
18150 for j=1 to lq(tn)
18160 oq(tn,j)=oq(tn,j+1)
18170 next j
18180 return
18500 for jj=22 to 27
18510 for j=1 to lq(jj)
18520 cp(jj-21,j)=0
18530 next j
18540 next jj
18550 for jj=22 to 27
18555 if lq(jj)<1 then 18610
18560 for j=1 to lq(jj)
18570 pn(jj,j)=int(oq(jj,j)/11+0.6)
18580 cp(jj-21,j+1)=cp(jj-21,j)+pt(pn(jj,j))
18590 next j
18600 cp(jj-21,lq(jj)+1)=cp(jj-21,lq(jj)+1)/3600
18610 next jj
```

```
18620 return
20100 if dx(tt)=1 then return
20110 poke dra,tt:poke dra,0:d(tt)=d(tt)*(-1)
20112 id(oq(tt,1))=ti/3600-tr(oq(tt,1))
20115 print "waiting time of";oq(tt,1);"on m/c";tt;"is";id(oq(tt,1))
20120 td=td+id(oq(tt,1))
20125 pn(tt,1)=int(oq(tt,1)/11+0.6)
20130 if dx(tt)=2 then return
20135 gosub 10000
20150 tf(oq(tt,1))=pt(pn(tt,1))+tm
20220 return
30000 if lq(30)<2 then return
30010 if rl(oq(30,1))=2 then 30025
30020 gosub 35000:goto 30030
30025 ff=8
30030 print "part";oq(30,1);"should return to storage";ff
30040 poke dra,60
30050 if peek(dra)<>188 then 30040
30060 if d(30)=1 then 30100
30070 poke dra,30:poke dra,0:d(30)=d(30)*(-1)
30080 gosub 10000
30090 if tm/3600>(ti/3600)-0.03 then 30090
30100 poke dra,30:poke dra,0:d(30)=d(30)*(-1)
30105 xb=ti:tp(oq(30,1))=xb-at(oq(30,1))*3600
30110 poke dra,60
30120 if peek(dra)=60 then 30110
30125 if ff=1 then 30160
30130 if d(ff+7)=1 then 30150
30140 poke dra,ff+7:poke dra,0:d(ff+7)=d(ff+7)*(-1)
30150 if ff=8 then 30295
30160 for l=ff+8 to 15
30170 if d(l)=-1 then 30190
30180 poke dra,l:poke dra,0:d(l)=d(l)*(-1)
30190 next l
30192 la(oq(30,1))=tp(oq(30,1))-al(pn(30,1))
30194 tp(oq(30,1))=tp(oq(30,1))/3600:la(oq(30,1))=la(oq(30,1))/3600
30196 print "throughput time of part    ";oq(30,1);"is=";tp(oq(30,1))
30198 print "production lateness of part";oq(30,1);"is=";la(oq(30,1))
30199 tu=tu+tp(oq(30,1)):tl=tl+la(oq(30,1))
30200 at(oq(30,1))=xb+w6(ff)*3600
30205 if pn(30,1)=2 or pn(30,1)=4 or pn(30,1)=6 or pn(30,1)=7 then 30210
30208 lc(oq(30,1))=al(pn(30,1))+at(oq(30,1))-pt(pn(30,1))-(1.7427*3600)
30209 goto 30220
30210 lc(oq(30,1))=al(pn(30,1))+at(oq(30,1))-pt(pn(30,1))
30220 lc(oq(30,1))=lc(oq(30,1))/3600:at(oq(30,1))=at(oq(30,1))/3600
30230 print "arrival time of a new part ";oq(30,1);"is=";at(oq(30,1))
30295 lq(ff)=lq(ff)+1:oq(ff,lq(ff))=oq(30,1)
30300 if lq(30)<1 then return
```

```
30305 lq(30)=lq(30)-1
30308 if lq(30)<1 then return
30310 for j=1 to lq(30)
30320 oq(30,j)=oq(30,j+1)
30330 next j:return
35000 ff=oq(30,1)-(int(oq(30,1)/11+0.6))*10
35010 pn(30,1)=int(oq(30,1)/11+0.6):return
40000 if ti>=(sr+ss) then 50000
40010 for tn=22 to 27
40020 if d(tn)=-1 then 40060
40030 if lq(tn)<1 then 40060
40040 if lq(30)>4 then 40070
40050 if ti>=tf(oq(tn,1)) then 40500
40060 next tn
40070 return
40500 print "part";oq(tn,1);"is done at location";tn
40510 if dx(tn)=2 and xx(tn)<=tf(oq(tn,1)) then 40514
40512 goto 40520
40514 dx(tn)=10
40520 poke dra,tn:poke dra,0:d(tn)=d(tn)*(-1):mo(tn-21)=mo(tn-21)+1
40550 lq(30)=lq(30)+1
40560 oq(30,lq(30))=oq(tn,1)
40570 rl(oq(30,lq(30)))=1
40575 gosub 18000
40580 m3=m3+1:goto 40060
41000 for ic=1 to 70
41150 if ti>=bo(ic) then 41200
41160 if mn(ic)=0 then 41180
41170 if ti>=bf(ic) then 41400
41180 next ic:return
41200 if t$(ic)="as" then 41610
41220 tj=mn(ic)+21:pn(tj,1)=int(oq(tj,1)/11+0.6)
41230 if d(tj)=-1 then 41255
41240 bo(ic)=tf(oq(tj,1)):bf(ic)=bo(ic)+du(ic)
41250 if bo(ic)<ti then return
41255 dx(tj)=1
41260 print "machine center";tj;"fails at";bo(ic)/3600
41270 bo(ic)=bo(ic)+999999999999:return
41400 tj=mn(ic)+21:pn(tj,1)=int(oq(tj,1)/11+0.6)
41440 print "failed machine center";tj;"is repaired at";bf(ic)/3600
41442 if lq(tj)<1 then 41460
41450 tf(oq(tj,1))=bf(ic)+pt(pn(tj,1)):xx(tj)=tf(oq(tj,1))
41460 dx(tj)=2:bf(ic)=bf(ic)+999999999999:return
41610 print "as/rs cart fails. failure number is";ic
41620 wl=du(ic)/3600:bo(ic)=bo(ic)+999999999999:return
45000 if lq(30)>4 then return
45010 poke dra,59
45020 if peek(dra)=59 then 45040
```

```
45030 return
45040 m4=m4+1:tn=29
45050 lq(tn)=lq(tn)+1:oq(tn,lq(tn))=oq(16,1)
45060 print "part";oq(tn,1);"is done at location";tn
45070 poke dra,tn:poke dra,0:d(tn)=d(tn)*(-1)
45080 gosub 10000
45090 if tm/3600>(ti/3600)-0.04 then 45090
45100 poke dra,tn:poke dra,0:d(tn)=d(tn)*(-1)
45110 if lq(16)<1 then 45150
45120 lq(16)=lq(16)-1
45130 if lq(16)<1 then 45150
45140 for j=1 to lq(16):oq(16,j)=oq(16,j+1):next j
45150 if lq(tn)<1 then 45190
45160 lq(tn)=lq(tn)-1
45170 if lq(tn)<1 then 45190
45180 for j=1 to lq(tn):oq(tn,j)=oq(tn,j+1):next j
45190 lq(30)=lq(30)+1
45200 oq(30,lq(30))=oq(tn,1)
45210 rl(oq(30,lq(30)))=2
45220 return
50000 ea=sm/sr:ia=1-ea
50005 for kn=1 to 6:em(kn)=rt(kn)*3600/sr:next kn
50010 for kn=1 to 6:im(kn)=1-em(kn):next kn
50040 el=(em(1)+em(2)+em(3)+em(4)+em(5)+em(6))/6:it=1-el
50050 for kn=1 to 8:df(kn)=df(kn)/n:next kn
50060 ml=ml/n:m2=m2/n
50070 print "3"
50080 print:print "statistical results"
50090 print:print "effectivity of as/rs cart=",ea
50100 print "idle rate of as/rs cart=",ia
50110 for kn=1 to 6
50120 print "effectivity of machine center";kn;"=";em(kn)
50130 print "idle rate of machine center";kn;"=";im(kn)
50140 next kn
50150 print "average effectivity of machine center cell=";el
50160 print "average idle rate of machine center cell=";it
50180 print:for kn=1 to 8
50190 print "fetch rate of storage area";kn;"=";df(kn)
50200 next kn
50210 for kn=1 to 6
50215 print "route rate to machine center";kn;"=";dt(kn)
50220 next kn
50250 print:print "fetch rate for machine center cell=";ml
50260 print "fetch rate for turning cell=           ";m2
50262 for kn=1 to 6
50264 print "total number of outputs from m/c";kn;"is=";mo(kn)
50266 next kn
50270 print "total number of outputs from m/cs=       ";m3
```

```
50280 print "total number of ouputs from turning cell=";m4
50285 print "total number of dispatches=              ";n
50290 print:for kn=1 to 8
50300 print "current queues of storage area  ";kn;"=";lq(kn)
50310 next kn
50320 print "current queues of retrieval gate=        ";lq(30)
50350 print "current queues of turning cell=          ";lq(16)
50360 print:for kn=22 to 27
50370 print "current queues of machine center";kn-21;"=";lq(kn)
50380 next kn
50390 print:for kn=1 to 8
50395 if lq(kn)<1 then 50435
50398 print "current queue sequence of storage area";kn
50400 for nn=1 to lq(kn)
50420 print oq(kn,nn);
50430 next nn
50432 print
50435 next kn
50440 print:for kn=22 to 27
50445 if lq(kn)<1 then 50485
50448 print "current queue sequence of m/c center";kn-21
50450 for nn=1 to lq(kn)
50470 print oq(kn,nn);
50480 next nn
50482 print
50485 next kn
50490 if lq(16)<1 then 50530
50492 print:print "current queue sequence of turning cell"
50495 for kn=1 to lq(16)
50510 print oq(16,kn);
50520 next kn
50530 print:print "current queue sequence of retrieval queue"
50535 for kn=1 to lq(30)
50550 print oq(30,kn);
50560 next kn
50570 print:print "total fetch time of as/rs=   ";sm/3600
50580 print:print "total processing time of m/c=";su/3600
50590 print:print "total throughput time(tp)=   ";tu
50600 print:print "total production lateness=   ";tl
50610 print:print "total idle time on machine centers=";td
50900 print#1,4:close1,4
50910 stop:end
51000 data 4.1649,190.38,53.1681
51050 data 7.2146,120.37,64.931
51100 data 2.0040,92.32,33.7202
51150 data 0.9759,17.93,8.7829
51240 data 1.2547,107.86,26.9762
51290 data 13.976,231.81,125.784
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51360 data 1.7601,26.93,15.8407
51362 data 0.2501,0.2155,0.2004,0.1886,0.1842,0.1761,0.1673,0.1637
51365 data 0.1348,0.1327,0.1448,0.1607,0.1760,0.1767
51370 data 0.1265,0.1243,0.1365,0.1523,0.1676,0.1683
51375 data 0.1198,0.1177,0.1298,0.1457,0.1610,0.1617
51380 data 0.1110,0.1088,0.1210,0.1368,0.1521,0.1528
51385 data 0.1023,0.1002,0.1124,0.1282,0.1435,0.1442
51390 data 0.0974,0.0953,0.1074,0.1232,0.1385,0.1392
51395 data 0.0909,0.0887,0.1009,0.1167,0.1320,0.1327
51400 data 0.0821,0.0800,0.0921,0.1080,0.1233,0.1240
51405 data 0.1773,0.1690,0.1623,0.1535,0.1448,0.1399,0.1334
51410 data 0.2017,0.2173,0.2275,0.2327,0.2427,0.2581,0.1229
51430 data 1,as,0,6.5998,0.9593
51440 data 2,as,0,13.1822,0.9593
51450 data 3,as,0,16.4602,0.9593
51460 data 4,as,0,33.7254,0.9593
51470 data 5,as,0,70.6326,0.9593
51480 data 6,as,0,81.1789,0.9593
51490 data 7,as,0,86.6583,0.9593
51500 data 8,mc,4,90.4847,17.5805
51510 data 9,as,0,98.8033,0.9593
51520 data 10,as,0,109.383,0.9593
51530 data 11,as,0,112.641,0.9593
51540 data 12,as,0,117.157,0.9593
51550 data 13,as,0,120.774,0.9593
51560 data 14,as,0,135.19,0.9593
51570 data 15,as,0,149.917,0.9593
51580 data 16,as,0,158.787,0.9593
51590 data 17,as,0,166.823,0.9593
51600 data 18,as,0,174.786,0.9593
51610 data 19,as,0,183.954,0.9593
51620 data 20,as,0,198.955,0.9593
51630 data 21,as,0,223.168,0.9593
51640 data 22,as,0,234.331,0.9593
51650 data 23,mc,2,248.774,30.3069
51660 data 24,as,0,251.072,0.9593
51670 data 25,as,0,269.286,0.9593
51680 data 26,as,0,282.811,0.9593
51690 data 27,as,0,290.735,0.9593
51700 data 28,as,0,309.259,0.9593
51710 data 29,mc,4,319.842,17.5805
51720 data 30,as,0,331.678,0.9593
51730 data 31,as,0,335.38,0.9593
51740 data 32,mc,5,340.789,46.1507
51750 data 33,as,0,341.75,0.9593
51760 data 34,as,0,384.621,0.9593
51770 data 35,mc,1,398.924,33.0536
51780 data 36,as,0,405.112,0.9593
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51790 data 37,as,0,409.014,0.9593
51800 data 38,as,0,415.552,0.9593
51810 data 39,as,0,422.459,0.9593
51820 data 40,as,0,426.136,0.9593
51830 data 41,as,0,457.355,0.9593
51840 data 42,as,0,463.874,0.9593
51850 data 43,mc,1,466.093,33.0536
51860 data 44,as,0,469.22,0.9593
51870 data 45,mc,2,471.658,30.3069
51880 data 46,as,0,488.148,0.9593
51890 data 47,as,0,508.795,0.9593
51900 data 48,mc,6,509.741,46.1507
51910 data 49,as,0,518.84,0.9593
51920 data 50,mc,3,520.211,103.6611
51930 data 51,as,0,527.53,0.9593
51940 data 52,as,0,555.265,0.9593
51950 data 53,as,0,558.333,0.9593
51960 data 54,as,0,561.601,0.9593
51970 data 55,as,0,569.941,0.9593
51980 data 56,as,0,584.327,0.9593
51990 data 57,as,0,597.647,0.9593
52000 data 58,as,0,608.553,0.9593
52010 data 59,as,0,616.881,0.9593
52020 data 60,as,0,631.42,0.9593
52030 data 61,as,0,638.195,0.9593
52040 data 62,as,0,646.628,0.9593
52050 data 63,as,0,652.123,0.9593
52060 data 64,as,0,660.027,0.9593
52070 data 65,mc,5,669.709,46.1507
52080 data 66,as,0,674.812,0.9593
52090 data 67,as,0,683.757,0.9593
52100 data 68,as,0,687.61,0.9593
52110 data 69,as,0,701.255,0.9593
52120 data 70,as,0,726.741,0.9593
ready.
```

```
2 open2,4,6:print#2,chr$(22)
5 open1,4:cmd1
10 print "3"
20 print "**************************************************************"
30 print "*                    physical simulation for fms               *"
40 print "*                       (value-fmfs)-(twk)                     *"
50 print "**************************************************************"
100 dim d(30),lq(30),oq(30,5),dx(30),xx(30),pn(30,5),tp(77),tr(77)
110 dim tf(77),w3(8,16),rl(77),tl(77),id(77),bo(70),bf(70),du(70)
120 dim la(77),at(77),cp(6,6),mn(70),t$(70)
130 dra=59471:poke 59459,127
150 poke 59467, peek(59467) and 227
160 poke 59468, peek(59468) and 31 or 224
170 for i=1 to 30:d(i)=-1:lq(i)=0:dx(i)=0:xx(i)=0:next i
210 for i=1 to 30:for j=1 to 5:oq(i,j)=0:next j:next i
220 for i=1 to 30:for j=1 to 5:pn(i,j)=0:next j:next i
230 for i=1 to 77:rl(i)=0:tl(i)=0:la(i)=0:tr(i)=0:next i
240 for i=1 to 77:at(i)=0:tp(i)=0:id(i)=0:next i
245 for i=1 to 6:mo(i)=0:dt(i)=0:rt(i)=0:rr(i)=0:pp(i)=0:next i
250 for i=1 to 70:bo(i)=0:bf(i)=0:du(i)=0:next i
260 for i=1 to 7:pt(i)=0:vl(i)=0:w6(i)=0:next i
275 for i=1 to 8:df(i)=0:next i
278 for i=1 to 8:for j=1 to 16:w3(i,j)=0:next j:next i
290 t=0:f=0:tt=0:ff=0
300 n=0:mm=0:m1=0:m2=0:m3=0:m4=0:tu=0:t1=0:td=0
310 ta=0:w1=0:w4=0.05:w5=0.07:ms=0:t3=0:t5=0:t6=0:t7=0:t8=0
330 for i=1 to 7:lq(i)=5:next i
340 for i=8 to 30:lq(i)=0:next i
350 j=1
360 for i=j to 7:oq(i,j)=i+(i-j+1)*10:next i
370 j=j+1
380 if j<=5 then 360
390 j=5:jj=j-1
400 for i=jj to 1 step -1
410 oq(i,j)=jj+70-11*(jj-i)
420 next i
430 j=j-1:jj=j-1
440 if j>=2 then goto 400
441 for i=1 to 7:for j=1 to 5
442 pn(i,j)=int(oq(i,j)/11+0.6)
443 next j:next i
445 for i=1 to 77:tf(i)=999999999999:next i
450 for i=1 to 7
460 read pt(i),vl(i),al(i)
470 pt(i)=pt(i)*3600:al(i)=al(i)*3600
480 next i
490 for i=1 to 8:read w6(i):next i
492 for i=1 to 8:for j=1 to 6
```

```
494 read w3(i,j)
496 next j:next i
498 for i=1 to 7:read w3(i,16):next i
499 for i=1 to 7:read ro(i):next i
500 print "do you wish to change the status of any output?"
510 print "enter 1 for yes, 2 for no": input x
520 if x<>1 then 580
530 print "enter desired output number": input g
540 if g<32 then 560
550 print "illegal output number (must be 0-31)":goto 530
560 poke dra,g:poke dra,0:goto 500
580 print "3":print "enter simulation run time in minutes."
590 input sr:sr=sr*3600:print "initialization has been completed."
620 ti$="000000":ss=ti
630 print "simulation starting time is ",ss/3600
650 for i=1 to 70
660 read i,t$(i),mn(i),bo(i),du(i)
670 bo(i)=bo(i)*3600+ss:du(i)=du(i)*3600:bf(i)=bo(i)+du(i):next i
700 gosub 30000
720 gosub 11000
730 gosub 13000
740 gosub 40000
750 gosub 45000
770 gosub 41000
780 goto 700
10000 tm=ti:return
11000 if lq(8)>0 then 11040
11005 for j=1 to 7
11010 if lq(j)<1 then 11018
11012 pn(j,1)=int(oq(j,1)/11+0.6)
11018 next j
11020 qq=0
11021 for j=1 to 7
11022 if lq(j)<1 then qq=qq+1
11024 next j
11025 if qq=7 then 11027
11026 goto 11030
11027 gosub 40000:gosub 30000:goto 11000
11030 gosub 17000:goto 11100
11040 f=8:goto 11130
11100 if oq(f,1)>10 and oq(f,1)<20 then 11160
11110 if oq(f,1)>30 and oq(f,1)<40 then 11160
11120 if oq(f,1)>50 and oq(f,1)<60 then 11160
11130 pq=0
11135 for k=22 to 27:if lq(k)>4 then pq=pq+1:next k
11140 if pq=6 then 11157
11145 t=22
11150 if lq(t)>4 then 11154
```

```
11152 kl=t-21:goto 11170
11154 t=t+1
11155 if t<=27 then 11150
11157 gosub 40000:goto 11000
11160 if lq(16)>4 then 11164
11162 kl=16:goto 11170
11164 gosub 45000:goto 11000
11170 gosub 12000:return
12000 gosub 10000
12006 if tm/3600<=(ti/3600)-wl then 12010
12008 gosub 40000:goto 12006
12010 wl=0:tl(oq(f,l))=ti
12015 print "current time=";ti/3600
12020 poke dra,28:poke dra,0
12040 poke dra,f+50
12050 if peek(dra)=f+50 then 12070
12060 goto 12040
12070 poke dra,28:poke dra,0
12072 gosub 10000
12074 if tm/3600>(ti/3600)-w3(f,kl) then 12074
12080 poke dra,f:poke dra,0
12090 t5=ti:print "loading part  ";oq(f,l);"from storage";f:t6=ti-t5
12095 gosub 10000
12100 if tm/3600>(ti/3600)-w4 then 12100
12102 poke dra,f:poke dra,0
12104 gosub 10000
12106 if tm/3600>(ti/3600)-w5 then 12106
12110 poke dra,28:poke dra,0
12130 t7=ti:print "returning with";oq(f,l);"from storage";f:t8=ti-t7
12140 poke dra,50
12150 if peek(dra)=178 then 12170
12160 goto 12140
12170 poke dra,28:poke dra,0:xa=ti
12180 ta=ti-tl(oq(f,l))-(wl+w3(f,kl)+w4+w5)*3600-t6-t8
12185 n=n+1:ta=ta/3600
12190 print "fetch time is ";ta
12200 ft=(ta+w3(f,kl)+w4+w5)*3600
12210 sm=sm+ft
12220 return
13000 if f=8 then 13040
13010 if oq(f,l)>10 and oq(f,l)<20 then 13500
13020 if oq(f,l)>30 and oq(f,l)<40 then 13500
13030 if oq(f,l)>50 and oq(f,l)<60 then 13500
13040 if d(16)=1 then 13070
13050 poke dra,16:poke dra,0:d(16)=d(16)*(-1)
13070 print "part";oq(f,l);"should be routed to machine center";t
13090 if t=27 then 13130
13100 if d(t-5)=1 then 13120
```

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13110 poke dra,t-5:poke dra,0:d(t-5)=d(t-5)*(-1)
13120 if t=22 then 13170
13130 for a=t-6 to 17 step -1
13140 if d(a)=-1 then 13160
13150 poke dra,a:poke dra,0:d(a)=d(a)*(-1)
13160 next a
13170 poke dra,t+10
13180 if peek(dra)=t+10 then 13170
13190 tr(oq(f,1))=xa/3600+ro(t-21)
13200 gosub 14000
13210 gosub 16000
13220 ml=ml+1:df(f)=df(f)+1:dt(t-21)=dt(t-21)+1:return
13500 if d(16)=-1 then 13520
13510 poke dra,16:poke dra,0:d(16)=d(16)*(-1)
13520 print "part";oq(f,1);"should goto turning cell"
13530 poke dra,40:if peek(dra)=40 then 13530
13540 t=16:tr(oq(f,1))=xa/3600+ro(7)
13542 gosub 14000
13545 gosub 16000
13550 m2=m2+1:df(f)=df(f)+1:return
14000 for tt=22 to 27
14010 if lq(tt)>0 and d(tt)=-1 then 14040
14020 next tt
14030 return
14040 gosub 20100:goto 14020
16000 lq(t)=lq(t)+1:oq(t,lq(t))=oq(f,1)
16010 if lq(f)<1 then return
16020 lq(f)=lq(f)-1
16030 for j=1 to lq(f):oq(f,j)=oq(f,j+1):next j
16040 return
17000 f=1
17010 if lq(f)<1 then 17110
17020 fl=f+1
17030 if fl>7 then return
17040 if lq(fl)<1 then 17060
17050 if vl(pn(f,1))<vl(pn(fl,1)) then 17100
17060 fl=fl+1
17070 if fl>7 then return
17090 goto 17040
17100 f=fl:goto 17060
17110 f=f+1
17120 if f>7 then 17000
17130 goto 17010
18000 nc=tn-21
18035 pn(tn,1)=int(oq(tn,1)/11+0.6)
18040 pp(nc)=pt(pn(tn,1))
18050 rt(nc)=rr(nc)+pp(nc):rr(nc)=rt(nc)
18060 rt(nc)=rt(nc)/3600
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```
18070 print "total processing time of m/c";tn;"is";rt(nc)
18080 su=su+pp(nc)
18090 ms=(sm+su/6)/(2*sr):t3=ti/3600
18100 print "current time","system effectivity"
18110 print t3,ms
18120 for j=1 to lq(tn):cp(nc,j)=0:next j
18130 if lq(tn)<2 then 18175
18140 for j=2 to lq(tn)
18150 pn(tn,j)=int(oq(tn,j)/11+0.6)
18160 cp(nc,j+1)=cp(nc,j)+pt(pn(tn,j)):next j
18165 cp(nc,lq(tn)+1)=cp(nc,lq(tn)+1)/3600
18170 print "remaining time of m/c queue";tn;"is";cp(nc,lq(tn)+1)
18175 if lq(tn)<1 then 18230
18180 lq(tn)=lq(tn)-1
18190 if lq(tn)<1 then 18230
18200 for j=1 to lq(tn)
18210 oq(tn,j)=oq(tn,j+1)
18220 next j
18230 return
20100 if dx(tt)=1 then return
20110 poke dra,tt:poke dra,0:d(tt)=d(tt)*(-1)
20112 id(oq(tt,1))=ti/3600-tr(oq(tt,1))
20115 print "waiting time of";oq(tt,1);"on m/c";tt;"is";id(oq(tt,1))
20120 td=td+id(oq(tt,1))
20125 pn(tt,1)=int(oq(tt,1)/11+0.6)
20130 if dx(tt)=2 then return
20135 gosub 10000
20150 tf(oq(tt,1))=pt(pn(tt,1))+tm
20220 return
30000 if lq(30)<2 then return
30010 if rl(oq(30,1))=2 then 30025
30020 gosub 35000:goto 30030
30025 ff=8
30030 print "part";oq(30,1);"should return to storage";ff
30040 poke dra,60
30050 if peek(dra)<>188 then 30040
30060 if d(30)=1 then 30100
30070 poke dra,30:poke dra,0:d(30)=d(30)*(-1)
30080 gosub 10000
30090 if tm/3600>(ti/3600)-0.03 then 30090
30100 poke dra,30:poke dra,0:d(30)=d(30)*(-1)
30105 xb=ti:tp(oq(30,1))=xb-at(oq(30,1))*3600
30110 poke dra,60
30120 if peek(dra)=60 then 30110
30125 if ff=1 then 30160
30130 if d(ff+7)=1 then 30150
30140 poke dra,ff+7:poke dra,0:d(ff+7)=d(ff+7)*(-1)
30150 if ff=8 then 30295
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30160 for l=ff+8 to 15
30170 if d(l)=-1 then 30190
30180 poke dra,l:poke dra,0:d(l)=d(l)*(-1)
30190 next l
30192 la(oq(30,1))=tp(oq(30,1))-al(pn(30,1))
30194 tp(oq(30,1))=tp(oq(30,1))/3600:la(oq(30,1))=la(oq(30,1))/3600
30196 print "throughput time of part    ";oq(30,1);"is=";tp(oq(30,1))
30198 print "production lateness of part";oq(30,1);"is=";la(oq(30,1))
30199 tu=tu+tp(oq(30,1)):tl=tl+la(oq(30,1))
30200 at(oq(30,1))=xb+w6(ff)*3600:at(oq(30,1))=at(oq(30,1))/3600
30230 print "arrival time of a new part ";oq(30,1);"is=";at(oq(30,1))
30295 lq(ff)=lq(ff)+1:oq(ff,lq(ff))=oq(30,1)
30300 if lq(30)<1 then return
30305 lq(30)=lq(30)-1
30308 if lq(30)<1 then return
30310 for j=1 to lq(30)
30320 oq(30,j)=oq(30,j+1)
30330 next j:return
35000 ff=oq(30,1)-(int(oq(30,1)/11+0.6))*10
35010 pn(30,1)=int(oq(30,1)/11+0.6):return
40000 if ti>=(sr+ss) then 50000
40010 for tn=22 to 27
40020 if d(tn)=-1 then 40060
40030 if lq(tn)<1 then 40060
40040 if lq(30)>4 then 40070
40050 if ti>=tf(oq(tn,1)) then 40500
40060 next tn
40070 return
40500 print "part";oq(tn,1);"is done at location";tn
40510 if dx(tn)=2 and xx(tn)<=tf(oq(tn,1)) then 40514
40512 goto 40520
40514 dx(tn)=10
40520 poke dra,tn:poke dra,0:d(tn)=d(tn)*(-1):mo(tn-21)=mo(tn-21)+1
40550 lq(30)=lq(30)+1
40560 oq(30,lq(30))=oq(tn,1)
40570 rl(oq(30,lq(30)))=1
40575 gosub 18000
40580 m3=m3+1:goto 40060
41000 for ic=1 to 70
41150 if ti>=bo(ic) then 41200
41160 if mn(ic)=0 then 41180
41170 if ti>=bf(ic) then 41400
41180 next ic:return
41200 if t$(ic)="as" then 41610
41220 tj=mn(ic)+21:pn(tj,1)=int(oq(tj,1)/11+0.6)
41230 if d(tj)=-1 then 41255
41240 bo(ic)=tf(oq(tj,1)):bf(ic)=bo(ic)+du(ic)
41250 if bo(ic)<ti then return
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41255 dx(tj)=1
41260 print "machine center";tj;"fails at";bo(ic)/3600
41270 bo(ic)=bo(ic)+999999999999:return
41400 tj=mn(ic)+21:pn(tj,1)=int(oq(tj,1)/11+0.6)
41440 print "failed machine center";tj;"is repaired at";bf(ic)/3600
41442 if lq(tj)<1 then 41460
41450 tf(oq(tj,1))=bf(ic)+pt(pn(tj,1)):xx(tj)=tf(oq(tj,1))
41460 dx(tj)=2:bf(ic)=bf(ic)+999999999999:return
41610 print "as/rs cart fails. failure number is";ic
41620 wl=du(ic)/3600:bo(ic)=bo(ic)+999999999999:return
45000 if lq(30)>4 then return
45010 poke dra,59
45020 if peek(dra)=59 then 45040
45030 return
45040 m4=m4+1:tn=29
45050 lq(tn)=lq(tn)+1:oq(tn,lq(tn))=oq(16,1)
45060 print "part";oq(tn,1);"is done at location";tn
45070 poke dra,tn:poke dra,0:d(tn)=d(tn)*(-1)
45080 gosub 10000
45090 if tm/3600>(ti/3600)-0.04 then 45090
45100 poke dra,tn:poke dra,0:d(tn)=d(tn)*(-1)
45110 if lq(16)<1 then 45150
45120 lq(16)=lq(16)-1
45130 if lq(16)<1 then 45150
45140 for j=1 to lq(16):oq(16,j)=oq(16,j+1):next j
45150 if lq(tn)<1 then 45190
45160 lq(tn)=lq(tn)-1
45170 if lq(tn)<1 then 45190
45180 for j=1 to lq(tn):oq(tn,j)=oq(tn,j+1):next j
45190 lq(30)=lq(30)+1
45200 oq(30,lq(30))=oq(tn,1)
45210 rl(oq(30,lq(30)))=2
45220 return
50000 ea=em/sr:ia=1-ea
50005 for kn=1 to 6:em(kn)=rt(kn)*3600/sr:next kn
50010 for kn=1 to 6:im(kn)=1-em(kn):next kn
50040 el=(em(1)+em(2)+em(3)+em(4)+em(5)+em(6))/6:it=1-el
50050 for kn=1 to 8:df(kn)=df(kn)/n:next kn
50060 m1=m1/n:m2=m2/n
50070 print "3"
50080 print:print "statistical results"
50090 print:print "effectivity of as/rs cart=",ea
50100 print "idle rate of as/rs cart=",ia
50110 for kn=1 to 6
50120 print "effectivity of machine center";kn;"=";em(kn)
50130 print "idle rate of machine center";kn;"=";im(kn)
50140 next kn
50150 print "average effectivity of machine center cell=";el
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50160 print "average idle rate of machine center cell=";it
50180 print:for kn=1 to 8
50190 print "fetch rate of storage area";kn;"=";df(kn)
50200 next kn
50210 for kn=1 to 6
50215 print "route rate to machine center";kn;"=";dt(kn)
50220 next kn
50250 print:print "fetch rate for machine center cell=";m1
50260 print "fetch rate for turning cell=             ";m2
50262 for kn=1 to 6
50264 print "total number of outputs from m/c";kn;"is=";mo(kn)
50266 next kn
50270 print "total number of outputs from m/cs=       ";m3
50280 print "total number of ouputs from turning cell=";m4
50285 print "total number of dispatches=              ";n
50290 print:for kn=1 to 8
50300 print "current queues of storage area  ";kn;"=";lq(kn)
50310 next kn
50320 print "current queues of retrieval gate=        ";lq(30)
50350 print "current queues of turning cell=          ";lq(16)
50360 print:for kn=22 to 27
50370 print "current queues of machine center";kn-21;"=";lq(kn)
50380 next kn
50390 print:for kn=1 to 8
50395 if lq(kn)<1 then 50435
50398 print "current queue sequence of storage area";kn
50400 for nn=1 to lq(kn)
50420 print oq(kn,nn);
50430 next nn
50432 print
50435 next kn
50440 print:for kn=22 to 27
50445 if lq(kn)<1 then 50485
50448 print "current queue sequence of m/c center";kn-21
50450 for nn=1 to lq(kn)
50470 print oq(kn,nn);
50480 next nn
50482 print
50485 next kn
50490 if lq(16)<1 then 50530
50492 print:print "current queue sequence of turning cell"
50495 for kn=1 to lq(16)
50510 print oq(16,kn);
50520 next kn
50530 print:print "current queue sequence of retrieval queue"
50535 for kn=1 to lq(30)
50550 print oq(30,kn);
50560 next kn
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50570 print:print "total fetch time of as/rs=   ";sm/3600
50580 print:print "total processing time of m/c=";su/3600
50590 print:print "total throughput time(tp)=   ";tu
50600 print:print "total production lateness=   ";tl
50610 print:print "total idle time on machine centers=";td
50900 print#1,4:close1,4
50910 stop:end
51000 data 3.9222,190.38,50.0702
51050 data 6.7942,120.37,61.1476
51100 data 1.8873,92.32,31.7554
51150 data 0.9190,17.93,8.2712
51240 data 1.1816,107.86,25.4043
51290 data 13.1617,231.81,118.455
51360 data 1.6575,26.93,14.9177
51362 data 0.2501,0.2155,0.2004,0.1886,0.1842,0.1761,0.1673,0.1637
51365 data 0.1392,0.1363,0.1471,0.1617,0.1756,0.1753
51370 data 0.1303,0.1274,0.1382,0.1528,0.1666,0.1664
51375 data 0.1232,0.1203,0.1311,0.1457,0.1596,0.1593
51380 data 0.1137,0.1108,0.1217,0.1363,0.1501,0.1499
51385 data 0.1045,0.1016,0.1124,0.1271,0.1409,0.1406
51390 data 0.0992,0.0963,0.1071,0.1217,0.1356,0.1353
51395 data 0.0922,0.0893,0.1002,0.1148,0.1286,0.1284
51400 data 0.0829,0.0800,0.0908,0.1055,0.1193,0.1190
51405 data 0.1838,0.1749,0.1678,0.1584,0.1491,0.1438,0.1369
51410 data 0.2017,0.2173,0.2275,0.2327,0.2427,0.2581,0.1229
51430 data 1,as,0,6.2152,0.9034
51440 data 2,as,0,12.4142,0.9034
51450 data 3,as,0,15.5011,0.9034
51460 data 4,as,0,31.7603,0.9034
51470 data 5,as,0,66.517,0.9034
51480 data 6,as,0,76.4488,0.9034
51490 data 7,as,0,81.6089,0.9034
51500 data 8,mc,4,85.2123,16.5561
51510 data 9,as,0,93.0463,0.9034
51520 data 10,as,0,103.009,0.9034
51530 data 11,as,0,106.078,0.9034
51540 data 12,as,0,110.331,0.9034
51550 data 13,as,0,113.737,0.9034
51560 data 14,as,0,127.313,0.9034
51570 data 15,as,0,141.182,0.9034
51580 data 16,as,0,149.535,0.9034
51590 data 17,as,0,157.103,0.9034
51600 data 18,as,0,164.601,0.9034
51610 data 19,as,0,173.236,0.9034
51620 data 20,as,0,187.363,0.9034
51630 data 21,as,0,210.164,0.9034
51640 data 22,as,0,220.677,0.9034
51650 data 23,mc,2,234.278,28.5410
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51660 data 24,as,0,236.443,0.9034
51670 data 25,as,0,253.596,0.9034
51680 data 26,as,0,266.332,0.9034
51690 data 27,as,0,273.794,0.9034
51700 data 28,as,0,291.239,0.9034
51710 data 29,mc,4,301.205,16.5561
51720 data 30,as,0,312.352,0.9034
51730 data 31,as,0,315.838,0.9034
51740 data 32,mc,5,320.932,43.4616
51750 data 33,as,0,321.837,0.9034
51760 data 34,as,0,362.21,0.9034
51770 data 35,mc,1,375.679,31.1277
51780 data 36,as,0,381.507,0.9034
51790 data 37,as,0,385.181,0.9034
51800 data 38,as,0,391.338,0.9034
51810 data 39,as,0,397.843,0.9034
51820 data 40,as,0,401.306,0.9034
51830 data 41,as,0,430.706,0.9034
51840 data 42,as,0,436.845,0.9034
51850 data 43,mc,1,438.935,31.1277
51860 data 44,as,0,441.88,0.9034
51870 data 45,mc,2,444.176,28.5410
51880 data 46,as,0,459.705,0.9034
51890 data 47,as,0,479.148,0.9034
51900 data 48,mc,6,480.039,43.4616
51910 data 49,as,0,488.609,0.9034
51920 data 50,mc,3,489.9,97.6210
51930 data 51,as,0,496.792,0.9034
51940 data 52,as,0,522.911,0.9034
51950 data 53,as,0,525.801,0.9034
51960 data 54,as,0,528.878,0.9034
51970 data 55,as,0,536.45,0.9034
51980 data 56,as,0,550.279,0.9034
51990 data 57,as,0,562.824,0.9034
52000 data 58,as,0,573.094,0.9034
52010 data 59,as,0,580.937,0.9034
52020 data 60,as,0,594.629,0.9034
52030 data 61,as,0,601.009,0.9034
52040 data 62,as,0,608.951,0.9034
52050 data 63,as,0,614.125,0.9034
52060 data 64,as,0,621.569,0.9034
52070 data 65,mc,5,630.687,43.4616
52080 data 66,as,0,635.492,0.9034
52090 data 67,as,0,643.916,0.9034
52100 data 68,as,0,647.545,0.9034
52110 data 69,as,0,660.394,0.9034
52120 data 70,as,0,684.396,0.9034
ready.
```