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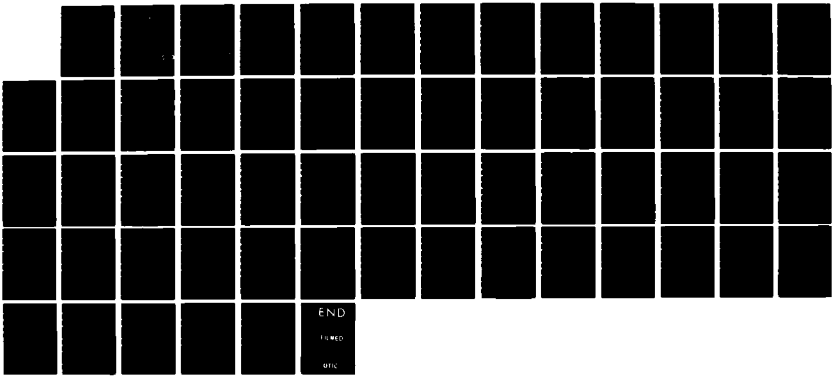

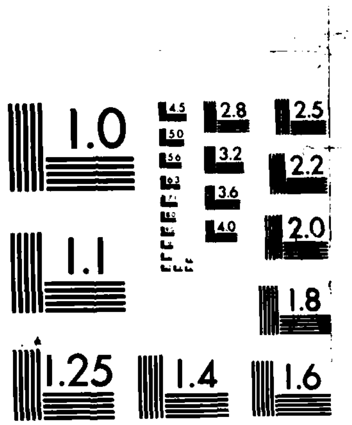

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FOR AUTOMATIC TEST SYSTEMS

THESIS

David A. Higgins
Squadron Leader, RAAF

AFIT/GLM/LSM/85S-34

DEPARTMENT OF THE AIR FORCE
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A STUDY OF JOB SCHEDULING FOR AUTOMATIC TEST SYSTEMS

THESIS

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Logistics Management

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Abstract

This study investigated the effects of different scheduling methods on the operational effectiveness of Automatic Test Equipment. The types of scheduling considered were first-in-first-out (FIFO), a modified FIFO where all components of the same type were processed in a batch, and a priority scheduling based on determination of the expected time to the next backorder, as predicted by renewal theory, with priority given to the component with the shortest expected time to a backorder.

The study was accomplished by constructing a simulation model of the Royal Australian Air Force ATE workshop at 492SQN in South Australia. The repair process was modelled from the time a component became unserviceable to the time it became serviceable again. The arrival process for components was assumed to be Poisson. The ATE testing of components was modelled in detail, but the physical repair and any spares delay were represented by a gamma distribution.

The study showed that, for this workshop, the different scheduling methods had little effect because the repair time and spares delay were relatively large , compared to the ATE testing time, and thus were the controlling influences in the system.

A STUDY OF JOB SCHEDULING FOR AUTOMATIC TEST SYSTEMS

I. Problem Statement and Background

Introduction

Automatic testing of electronic components by computer controlled test equipment is now commonplace. The speed and flexibility of Automatic Test Equipment (ATE) make it very attractive where a large number of components must be tested and where those components may vary in configuration, as occurs in aircraft maintenance. However, the large variety of job priorities and varying test times have led to a problem in work scheduling.

Problem Statement

The Royal Australian Air Force (RAAF) utilizes ATE for the maintenance of a significant portion of the electronic equipment in service on its more modern aircraft. For some years now, the RAAF has been concerned that these ATE are not utilized efficiently. The Directorate of Maintenance Policy (DMP) of the RAAF requested that a study of ATE production planning be undertaken to produce guidelines that would enable efficient and effective use of ATE (6). The study had initially to determine methods of measuring ATE utilization/effectiveness and then to determine a production planning system based on set up and test times, required turn around times, and unit holdings of components. In particular, the possibility of batching component testing to reduce time absorbed by reconfiguration was to be investigated.

Background

The problem is essentially one of scheduling multiple queues (the variety of components) and multiple servers (the test stations). The available literature was reviewed for general information on multi-machine, multi-job scheduling and specifically for analysis and models of ATE. A suitable means of calculating job priority based on the expected number of failures was also required.

Maintenance Scheduling

Surprisingly little literature is available on the subject of maintenance scheduling. Numerous texts, such as Baker's Introduction to Sequencing and Scheduling (2), address scheduling in a production environment. Although many of these principles can be applied to the maintenance environment, they tend to consider the case of a machine that is dedicated to one task or is set up for a long batch run. An ATE can be, and often is, reconfigured many times per day to handle a large variety of maintenance tasks.

Newbrough (12) discusses maintenance management from a more basic viewpoint and offers the following basic principles for maintenance scheduling:

1. Schedules should be based on what is most likely to happen, rather than what we would like to see happen.

2. Schedule revision should be expected.

3. A schedule is a means to an end, not an end in itself.

4. Delivery promises should allow for reasonable lead times for materials, paper work, and planning, as well as for machine time and labour.

5. Records of workloads or backlog against machines, departments or manpower groups should include a minimum of detail needed to predict deliveries and provide a plan of action.

Newbrough recommends that approximately 75% of maintenance activity be scheduled and the rest reserved for emergencies (12:137). This ratio will depend on the actual maintenance operation (12:137,11:145). This criterion is also utilized by the RAAF, although it is not published policy.

Previously Developed Models of Automatic Test Equipment.

A paper presented at the 1969 Automatic Support Systems Symposium outlined a general simulation model for ATE activity (15). This model assumed a Poisson distribution for the arrival rate of the unserviceable components and a normal distribution of component test times. The station workload was considered to consist of a single type of component, and each component was assumed to require the same ATE reconfiguration time prior to test.

A 1982 AFIT thesis by Husby, Webb and Bryson developed a simulation model of the ATE system which was to be procured to support the F-16 program (4). In this study, the arrival distribution for an F-16 component requiring ATE testing was analyzed and found to be Poisson. The authors recognized that their study was limited by having only considered one type of component and recommended further research be carried out to determine the model validity for the full range of F-16 components (4:76).

Another AFIT thesis, conducted by Roark in 1983, carried out a similar investigation for the B-1B bomber program (14). Roark attempted to develop both analytic and simulation models, but the analytic model required many simplifications and the results obtained when compared with the simulation output were determined to be unrealistic. Therefore, the bulk of the research effort was carried out with the simulation model (14:73). This model is much more detailed than the previous two models and considerable sensitivity analysis was undertaken. Roark analyzed the data for many types of components and used these in his model rather than using a single, representative component as the previously mentioned studies had done. The arrival of components was again found to conform to the Poisson process. This is the first model found where queue discipline had at least been mentioned; it was considered to be "approximately on a first-come, first-serve basis (with some) adjustment to allow for a higher priority" (14:19).

ATE Utilization Measures

The operational definitions of "ATE utilization" and "ATE efficiency" were not clear in the original RAAF research request. Both the Sauder and Miller and the Roark simulations measured ATE efficiency using the turn around times achieved for components. Use of turn around time as an efficiency measure may not be correct when studying scheduling algorithms as it may be advantageous to delay repair of items with a high mean time between arrivals (MTBA) to ensure repair of low MTBA items, thus avoiding shortages of critical items.

The most apparent goals of ATE scheduling are to maximize throughput of components, minimize station utilization time, minimize average component turn-around time and minimize backorders (a backorder occurs when there is a zero stock level and a further demand occurs). These goals can conflict; for example, throughput may be able to be maximized by testing only simple components with short ATE run times, but this may cause backorders of other items. The ultimate goal of the scheduling algorithm must be to maximize fleet readiness, but the relationship between readiness and such variables as backorders and turn around time is too complex to be addressed in this study. However, modern analytical supply models, such as Dyna-Metric, which have been developed after much research, are based on the premise that readiness is a function of the expected number of backorders, and they calculate a readiness measure from the probabilities of backorders occuring for each item on an aircraft (8). As the ATE workshop is a part of the supply system, similar goals can be applied to its operation. Thus, minimization of backorders will be used as the major comparison measure between different scheduling algorithms in this study, although the other goals will still be considered.

Priority Calculation

In order to determine a priority for testing components on the ATE, it is necessary to estimate the time to the next backorder. Components with existing backorders must still be tested first. However, if there are no backorders, testing of the components with the shortest expected time to a backorder should minimize the probability of a backorders occurring. Thus, one of the scheduling methods examined in this study will give priority to testing components with the shortest expected time to a backorder, based on renewal theory.

Renewal theory concerns the "study of stochastic systems whose evolution through time is interspersed with renewals, times when, in a statistical sense, the process begins anew (9:167)". One of the objectives of renewal theory is to compute the expected number of renewals in a time interval. Karlin and Taylor in their First Course in Stochastic Processes review renewal theory and specifically examine the Poisson distribution (9:219). Their analysis shows that for a Poisson process, the expected number of renewals (failures) in a time interval (0-t] is equal to the inter-arrival rate multiplied by the length of the period, t (9:221). Thus, the expected time to the next backorder for each type of component can be calculated by dividing the remaining stock level plus one (to get to a backorder level) by the interarrival rate.

Summary

A number of models have been developed for simulation of ATE operation. Most have been directed towards determination of the numbers of ATE required to support a program. Little research has been carried out into the management principles for operation of an ATE, a quite complex operation. All the models reviewed had accepted the Poisson distribution to represent the interarrival time of components.

There is no accepted measure of ATE effectiveness, although several can be proposed intuitively. As an ATE is essentially a part of the supply system, measures used in supply models will also apply to the ATE system. Current supply models view readiness as a function of backorders, so the number of backorders was used as the comparitive measure of effectiveness between the different scheduling algorithms proposed in this study.

Research Questions

The research questions posed to carry out this study were:

a. Would scheduling of jobs in order of increasing expected time to the next backorder improve ATE effectiveness?

b. Would the time saved in ATE reconfiguration by processing of components in batches improve ATE effectiveness?

II. Methodology

This study models the RAAF's ATE facility at No 492 Squadron (492SQN) in South Australia. The shop has two AN/USM-449 ATEs and is the test and repair facility for many components in the RAAF's P-3C Orion aircraft. The repair process for components that require ATE testing was modelled from the point a component became unserviceable to the point it became serviceable again. Figure 1 is a flowchart of the process.

Simulation Methodology

Most of the general simulation texts (3,6,13) describe the steps to be undertaken in a simulation process. The steps followed in this study are based on those in Banks and Carson (3:11-15) and Pritsker (13:10-11), which are very similar.

The first steps in a simulation are problem identification and setting of objectives. In fact, these steps should have been carried out even before simulation is selected as the research method. Chapter I of this study covered these steps and explained why simulation was selected.

Data Collection and Analysis

Data collection is included as a sequential step in most methodologies, but it is actually an on-going process throughout all of

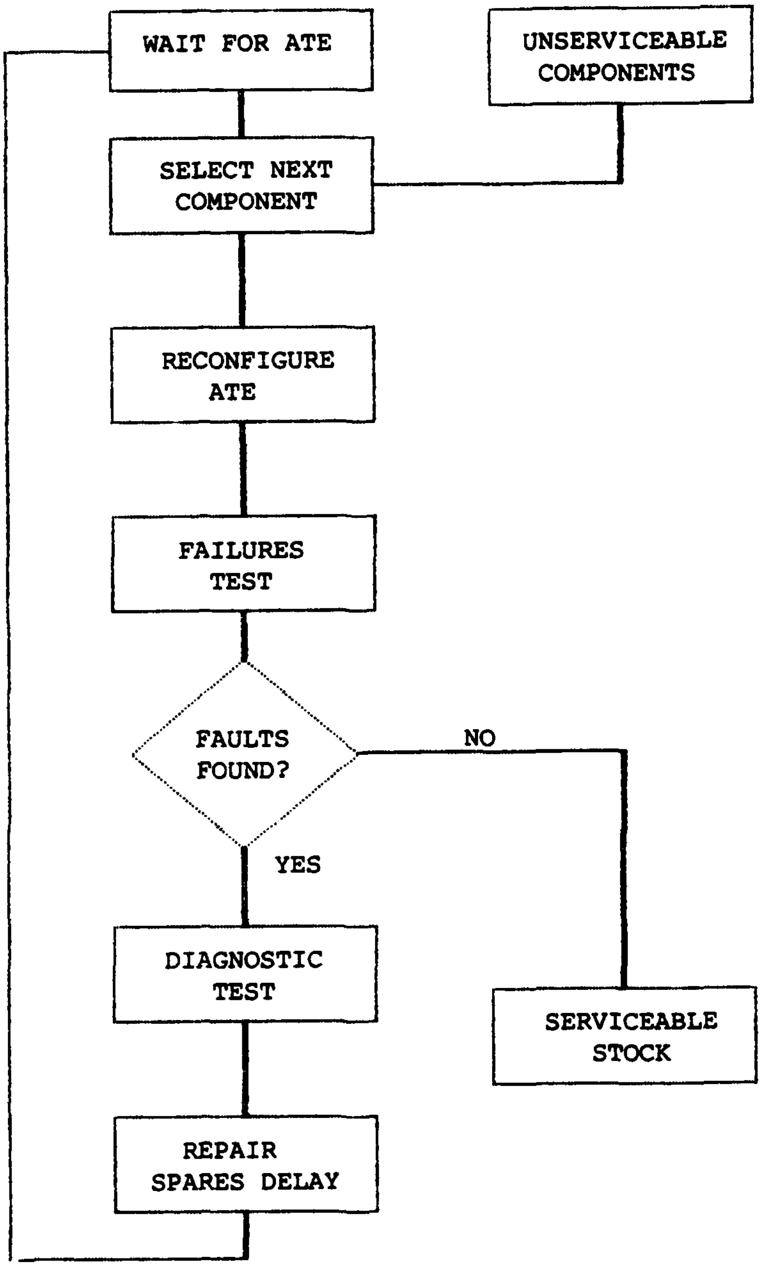

Figure 1. ATE System Flowchart

the early stages of a simulation study. For this study, some data were already available from the records of earlier attempts by the RAAF P-3 Program Office to determine ATE requirements. Other data were obtained from the RAAF's Computer Aided Maintenance Management (CAMM) System at 492SQN, from the centralized Maintenance Analysis and Reporting System (MAARS), from job records collected in the ATE workshop itself and from interviews with ATE workshop personnel.

Job histories obtained from the CAMM system provided information over a one year period on the mean time between arrivals (MTBAs) and delays in calendar days. Of approximately seven hundred component types that can be serviced by the ATEs, one hundred and five were observed. Only ninety four of these could be modelled due to limitations of the simulation language. The CAMM data enabled accurate determination of MTBAs for the high arrival rate items which form the major portion of the ATE workload, however, there are many components with arrival rates of one or two per year. The best available data for these items was from the MAARS system, which gave number of failures per year over the five years that the ATEs have been operational. The eleven components discarded from the study had only one or no other arrivals in the previous five years. All the others had one to two arrivals per year and were given a mean interarrival rate of three quarters of a year to approximate this. This inaccuracy was undesirable, but unavoidable, and was not expected to affect the study markedly as the data for the components forming the major part of the ATE workload was accurate.

The CAMM data also provided information on the delays a job might be subject to between ATE tests. The original objective was to develop an individual delay distribution for each of the high arrival rate components and a generalized distribution for the remainder. Histograms showed the delay data exhibited the general shape of either the exponential, Weibull, or gamma distributions. However, statistical analysis using the Kolmogorov-Smirnoff (K-S) goodness-of-fit test could not reject any of these distributions for individual component types, probably due to the small number of observations per type. The delay data for all the components was then pooled and analysed using the K-S test again. This time the exponential and Weibull distributions were rejected, but the gamma distribution, with a shape parameter of 0.7 and a scale parameter of 92.75, was accepted at a confidence level of ninety five percent.

Data for the actual ATE job process was obtained from the ATE workshop records and from telephone interviews with ATE workshop personnel. The percentages of jobs taking each of the various possible paths through the process were obtained by analysis of shop job records. The time taken for the failures test on the ATE was obtained from the P-3 USM-449(V) Master Test Program Set Index (6). The time taken for the diagnostic test is variable, depending on the faults found, and is not available from any records. Workshop personnel recorded ten diagnostic test times for various components and found them to be in the order of three to four times the failure test time. As there was not sufficient data for analysis, these estimates were used in a uniform distribution to represent the diagnostic run time. All other data used in the model was estimated by workshop personnel.

Model Building and Coding

The next steps were to build and code the model representing the system. The model was developed in SLAM II, a FORTRAN based, general purpose simulation language. A detailed description of the model is in Chapter III.

Verification

Model verification is the process of establishing that the computer program executes as intended. As mentioned in the previous paragaraph, the model was developed in stages, so each stage could be tested before progressing. Structured programming techniques of coding in discrete blocks of code with headings and comments to ensure readability were followed. Extensive use was also made of the TRACE feature in the SLAM language, which allowed the printing of the trail of the components as they were processed through the simulation model. Initially only one component was placed in the system and tracked, with significant variables printed out and calculations checked by hand for accuracy. The number of components was increased to two and then five to ensure the code operated correctly with both ATEs loaded.

Validation

Model validation is the process of comparing the model to the real system to determine whether a reasonable representation has been achieved. No model can ever totally represent the system under study, and the model user has to judge when the model is sufficiently accurate for its planned use, and when any increase in model accuracy is no longer worth the time and effort it will involve.

A number of techniques are described in the texts for validation of simulation models. A widely accepted approach uses three steps:

1. Build the model with high "face validity",
2. Validate model assumptions, and
3. Validate input/output transformations (3:384-385).

Face validity refers to constructing a model that appears reasonable to people who have knowledge of the system. The author of this study was in charge the 492SQN ATE workshop for over a year and therefore has personal knowledge of the system under study. Also, the steps for the ATE job process used in the simulation were discussed in detail with the ATE workshop technicians, who agreed they were highly representative of the actual job process.

Validation of model assumptions refers to validation of system operational assumptions and data assumptions. The data assumptions, such as the use of a gamma distribution to represent the time taken for obtaining spares and repairing the component, have already been covered in the data collection step. The only significant aspect of system operation being modelled is the process currently being used by the workshop personnel to select the next job for testing. This could not be modelled accurately as, once the crisis jobs with backorders or no stocks have been processed, selection becomes intuitive, based mainly on MTBA considerations, but also on how many of a job type are waiting and how long jobs have been waiting. The "crisis management" was incorporated into the simulation, but once these types of jobs had been processed a first-in-first-out (FIFO) rule was used. However, the ATE workshop is operating near peak capacity and crisis management is the norm rather than the exception. Thus, the secondary FIFO selection rule was used initially with a view to refining it if the model outputs indicated this was necessary.

Validation of input-output transformations should preferably be achieved by witholding some of the data for statistical comparison with the model output. Due to the small amount of data available, this could not be done and the only validation of input-output transformations was to observe if the dependent outputs, such as the number of components processed per day and the percentage of jobs in delay, was similar to those achieved in the workshop. Also, the system was known to be near peak capacity, and a small increase in arrival rate or processing time should have caused the system to overload and the lengths of queues to continually increase.

The lack of a totally accurate representation of the 492SQN ATE system was not considered detrimental to the study. First, the system is very dynamic with modifications to components and the ATEs changing the system characteristics regularly. Second, the study is a comparison of scheduling techniques, and any reasonable representation of the system will be sufficient for comparison purposes.

Experimentation

Three types of scheduling algorithms were examined:

a. The "crisis management" algorithm currently used by 492SQN. Top priority is given to jobs for which backorders exist, then to jobs for which there are zero stock levels. For both of these cases jobs which have been through the repair workshop and are awaiting a serviceability check are tested first. The next level of selection is subjective and cannot be modelled easily, so a FIFO rule was used in its place.

b. A batch version of the above rule was tested in which the first job was selected using the same criteria, but then all queued components of the same type were processed before a new component selection was made.

c. Selection by assigning each job a priority based on the expected time before a backorder, calculated using the renewal function for the Poisson process. Components currently in a backorder situation were tested first. If there were no backorders then the job with the minimum expected time to a backorder was tested.

Analysis of Results

The output of a simulation is stochastic in nature and each simulation run gives a point estimate of the variable under consideration (3:408). To use classical statistical techniques, a sample of the population of possible output values must be obtained. One way of achieving this is to make a number of simulation runs with the random number generators initialized differently for each run. For steady-state systems this is complicated by the need to allow a warmup period before each run to overcome any any bias in the initial conditions, such as zero length queues at time zero. As an alternative to making many runs and going through the warmup for every run, the method of batch means can be used in steady-state simulations (3:440). Using this method, the statistics maintained by the simulation language are cleared after the warmup period and then statistical summaries are taken at regular intervals (i.e. in batches) to obtain the sample values.

To use this method, the intervals chosen must be sufficiently large to avoid any autocorrelation between the batches caused by the values at the end of one period being the initial conditions for the next period. There is no widely accepted method for choosing an appropriate interval, and those that do exist use an iterative process of increasing the interval length over successive runs and calculating the autocorrelation coefficients between successive batches (3:440). This is a lengthy process and there was not sufficient time in this study to carry out the analysis so a batch interval of one year was chosen because it is significantly greater than most of the values used in the simulation, thus minimizing the interaction between one period and the next.

All statistical analysis was conducted at a confidence level of ninety five percent. Analysis of variance (ANOVA) was used to determine if there was any difference in the means of the samples obtained from simulation of each of the scheduling methods. The ANOVA hypotheses are:

H_o: all the sample means are the same

H_a: at least two of the sample means differ.

The only valid conclusion that can be drawn at a ninety five confidence level is to reject the null hypotheses and accept the alternative that at least two of the means differ. If the null hypothesis is rejected, indicating that at least two of the sample means differ, confidence intervals for the difference between the means of each of the samples must be calculated to determine which of the samples are different. If a confidence interval does not contain zero, the two samples can be accepted as coming from different populations, implying that the scheduling methods which resulted in the samples are different.

III. Model Description

General Description

As mentioned in Chapter II, the ATE system was modelled in the SLAM II simulation language. The standard network commands of SLAM can simulate such aspects of a system as creation of entities (unserviceable components), the entities waiting in queues (until an ATE becomes available), processing of entities by a resource (an ATE), plus many of the decision processes associated with systems. Once the user models the process, SLAM controls the flow and scheduling of entities through the system. In some cases, the network routines do not exactly represent the process being simulated and the user must use discrete simulation techniques, basically FORTRAN subroutines, to achieve the desired effect.

In the ATE workshop model, the component arrivals, the ATE testing process, and the repair/spares delay time were all simulated using network commands. However, FORTRAN subroutines were used for the selection and transfer of components from the queues of jobs to the ATEs. This had several advantages. Coding of the scheduling algorithms in FORTRAN was much easier than using SLAM network commands, and verification of the operation of the routines was made easier by printing out data from within the subroutines. In addition, some statistics, such as the number of backorders per type of component, were easier to collect within the subroutines. Having the scheduling algorithms as separate routines also made the various simulation runs easier. Generally, only minor changes were made to the network portion of the model and then a simulation run with each scheduling algorithm was carried out.

Network Description

Appendix A is a computer code listing of the network portion of the model. In the comments in the code, the components are referred to as LRUs (line replaceable units) for brevity, although they could actually be either line replaceable or shop replaceable units. The network portion of the model can be divided into five major sections;

a. Initialization of stock levels for each type of component,

b. Arrival of unserviceable components,

c. ATE processing of components,

d. Spares and repair delays, and

e. ATE work shifts

Initialization of Stock Levels

The section of code headed "Initial Stock Levels" initializes the stock levels of the components and also sets to zero the various counters used during the simulation. Initially, there are no unserviceable components in the system, hence the need for a warmup period to allow the model to reach a steady state representing the normal state of the real workshop.

Arrival of Unserviceable Components

The arrival of unserviceable components is simulated in the section headed "LRU Characteristics". A separate section of code was needed for each type of component, although only the first component is shown in appendix A. One of each type of component was created at time zero as part of the warmup process to load the system with unserviceable components awaiting testing. Further unserviceable components are created at times determined by the simulation processing in accordance with the mean time between arrivals given in the exponential distribution. Each unserviceable component carries with it attributes (essentially variables) identifying such things as the type of component, its time of arrival (to allow calculation of turn around time), and its progress through the repair process.

As each unserviceable component arrives, the stock level of that type of component is decremented and, if necessary, the number of stockouts are incremented. A check is made to see if an ATE is available immediately. If not, the component is held in a queue until it is selected for testing.

ATE Processing

The sections of the code headed "ATE #1" and "ATE #2" represent the actual processing of components by the ATEs. Figure 2 is a flowchart of this section of the model. When a component enters the ATE for testing, the time of arrival is recorded for statistical collection of ATE

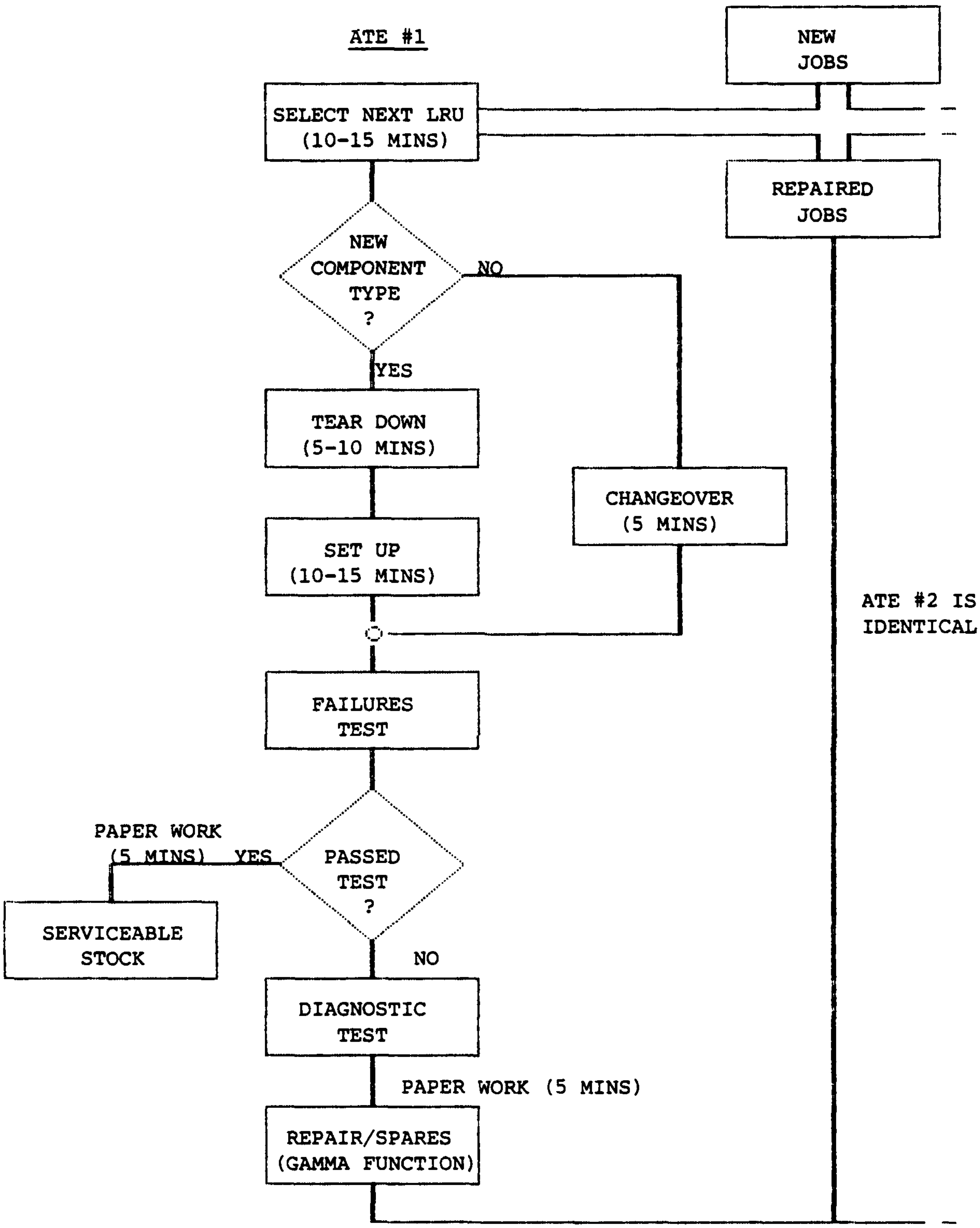

Figure 2. Flowchart of ATE Model

processing time. If the component is the same type as the one previously tested on the ATE, only a five minute changeover time is needed. Otherwise the ATE must be "torn down" (the current interface card and cables removed and stored), a new interface and cables installed, and the new job connected to the ATE. A test to see if any failures can be detected is then made. In approximately six percent of the cases, no faults can be found and the item is returned to serviceable stock. The remainder are subject to a diagnostic test to determine which of the sub-components may have caused the failure.

At this stage, the job will go to the repair workshop for replacement of the potentially failed components. In the real system, jobs may go through the test and repair cycle a number of times, but this was impossible to simulate as there was no data available on the number of cycles made. Also, the delay data was for a total job, so to use the gamma distribution correctly, the delay period had to be calculated once and then apportioned between the number of repair cycles. The simulation model assumed that no more than two repair cycles are made and that the spares delay and repair period was the same for both cycles. The model logic decides before the job leaves the ATE section of the model whether it is to have one or two repair cycles and it is routed to the appropriate part of the repairs section of the model so that an appropriate delay can be applied.

When the repair on the job is complete, it returns to the ATE for a serviceability check. If it passes this check, the component is returned to serviceable stock. If it fails the check it goes through the repair cycle again. A flag is used to determine how many repair cycles will be made. Components sent for a single repair cycle return to the ATE section with the flag set to one and will only be given a failures test, which they "pass", and then leave the network via commands that update the number of LRUs in the system, the stock level of the component, the job turn around time, and the number of backorders that have occurred. Jobs requiring two repair cycles return to the ATE the first time with the flag set to 0.5. They receive both failure and diagnostic tests again and go for a second repair cycle. The second time, they return with the flag set to one and receive only a failure test before leaving the system. These jobs are also subject to changeover time or teardown and setup time for the ATE.

As the job leaves the ATE section of the model, it passes through a statements that free the ATE for another job and call the FORTRAN subroutine currently being used for scheduling. This routine searches the queues of jobs and transfers the selected job directly to the start of the ATE section. If no jobs are waiting, then the next job arriving will take the free ATE.

Repairs

The repairs section of the model delays the job for an appropriate time to represent the repair time and any spares delay. A delay time is selected in accordance with the gamma function determined in data analysis. If the job will only go through the repair cycle once, the full delay is applied immediately. If the job is to be repaired twice, the delay time is calculated and stored on the first cycle, then half the delay is applied immediately and the other half when the item returns for the second cycle.

ATE Work Shifts

Another section of code was required to simulate the ATE workday. From squadron records, the average time an ATE spent on aircraft component maintenance per working day was 5.17 hours. However, the length of the day for each individual ATE could vary significantly depending on the time taken for the last job of the day, or whether a new job will be started when the end of the day is near. A suitable time for deciding not to commence a new job had to be chosen so that, given all jobs will overrun the selected time, the average day came to be near 5.17 hours, as shown in Figure 3.

```
0---------------------------------------------T----1-----M-----2
```

0 = start of day
T = time after which no more jobs are accepted
1 = first ATE finishes job
2 = second ATE finishes job
M = mean length of day

Figure 3: ATE Shop Workday

The time, T, was determined iteratively and a value of 4.6 was chosen, although plus or minus 0.1 of an hour made little difference. The batch scheduling algorithm did shorten the average length of ATE jobs and, consequently the average length of the day, but this was determined to be statistically insignificant during sensitivity analysis.

Interarrival rates, spares delay and repair time were all calculated in whole calendar days and hence weekends and public holidays had to be included in the model. There were 248 working days in 1984, leaving 117 non working days to be divided amongst 52 weekends, giving the 2.25 days per weekend figure used in the model. This equal allocation of holidays throughout the year is reasonable because the shop rarely shuts down completely for any long period.

FORTRAN Routines

SLAM is actually written as a subroutine that is called from a main FORTRAN routine. This enables the user to write a main routine with added subroutines which can then be called from within SLAM. The main routine used for this simulation is shown in Appendix B, along with each of the subroutines that were appended to it for the various types of scheduling studied.

FIFO Routine. The first subroutine simulated the backorder/zero stock/FIFO type of scheduling, which represents the scheduling currently used by 492SQN. This routine first looks for an item where the stock level is below zero, indicating a backorder exists. The queue of components that have already been through the repair cycle is searched first because these items have the most chance of satisfying the backorder quickly if they pass the serviceability check. The search is conducted in a cyclic manner through the types of components to ensure that no low MTBA component will dominate the system and allow backorders for other items to build up. If no suitable component can be found in this queue, then the queue of newly arrived jobs is searched. If no backorders exist, then the queues are searched for components with a zero stock level in the same manner as for backorders. Finally, if a suitable component has still not been selected, the first job in the queue of repaired components is taken or, if that is empty, the first new job.

Batch Routine. The batch routine is identical to the FIFO routine except that the queues are searched first for a component of the same type that has just been tested.

Priority Routine. The priority routine searches first for backorder items in the same manner as the previous two routines. If none is found, the component with the lowest expected time to a backorder in either queue is selected. If two items are found with the same priority, but in different queues, the one which has been through the repair cycle is given preference. This routine also re-calculates the priority of each job on a daily basis, at the end of the day. The end of the day was chosen because the re-calculation would be a large task that would require computer support. The RAAFs CAMM system maintains most of the data required for the calculations and the customary time for such jobs to be scheduled on the system is in the evening.

Testing

Warmup. The warmup period required for the system to stabilize was determined by plotting the number of components in the system and in the queues. The graphs levelled off and maintained mean levels consistent with those seen in the workshop after the equivalent of two years running. To ensure all effects of the warmup period had been removed, a warmup period of three years was used in the final runs. This warmup period also carried with it the implication that the experiment was a completely randomized design as, by the time statistical collection commenced, the different component selection techniques had created different starting configurations for the batches.

Sensitivity Analysis. Sensitivity analysis was performed mainly as a model validation technique. Variables tested for sensitivity were length of workday, ATE processing time, and component arrival rate. The effects of each of these on number of backorders, throughput, and ATE utilization were examined.

Varying the length of the ATE workday was expected to increase the throughput of the ATEs. However, when the length of the day was varied by five percent in either direction the difference in throughput was found to be statistically insignificant. This was difficult to explain, but is believed to be due the way the ATEs are shut down at the end of the day. To achieve the variation in total day length it was necessary to vary the time at which no more jobs will be accepted for processing. Unless this change significantly increases the probability of a new job being accepted each day, throughput is unlikely to be affected. The average length of a job on the ATE was 1.3 hours and the time at which the ATEs were shut down was varied between 4.4 and 4.8 hours. On an "average" day, the ATEs will be approximately half way through the fourth job of the day at the time the decision point for taking an extra job is reached. Thus it is unlikely that any small variation would affect the probability of selecting another job on a daily basis. This is supported by the operation of the ATE workshop where a significant increase in throughput can only be achieved by working an extra half to full shift for an extended period.

Similar analysis was carried out for the length of ATE jobs by varying the job selection time, thus affecting all jobs equally. Small variations in the job time did not have any effect on the throughput, for the same reasons the variation in length of the day had little effect. However, as expected, job length could be increased to the point where the system became overloaded causing the queue lengths to continually increase with time. Increasing the arrival rate of components by more than ten percent also caused the system to overload. The relatively small increases in either job length or arrival rate needed to overload the system were indications of the known lack of spare capacity in the workshop at 492SQN.

IV. Analysis and Findings

Simulation runs were made with each of the types of scheduling algorithm. Each run had a three year warm up period followed by thirty one batches of one year each. Thirty one batches was chosen because it gave sufficient numbers of samples for all the statistical techniques used and also because longer runs became prohibitive in their use of computer time.

Analysis

Sample means and ANOVA tables for each of the utilization measures are shown in Table 1. For all of the analyses the test statistic (obtained from F-tables) for comparison, $F_{0.05(2,30)} = 3.32$, is the same. In all cases the calculated F-statistic is less than the test statistic so the null hypotheses that the sample means were the same could not be rejected, indicating that there is no difference between any of the scheduling methods. This result was not entirely unexpected as the dominant feature in the system is the delay time. Although repair time and spares delay are combined in this model, the spares delay is known to be the significant factor in the real system.

The mean of the gamma distribution used to represent the delay was 43.7 days or 1049 hours. The simulation results showed the mean time spent waiting in queues for the ATE was in the order of 80 hours for repaired jobs and 150 hours for new jobs. It is difficult to compare the effects of this ten-fold difference in mean waiting time because the

TABLE 1

Simulation Results

Backorders

Sample Means:		
FIFO	195.80	per year
Batch	202.06	" "
Priority	201.12	" "

ANOVA	Sum of Squares	Degrees of Freedom	Mean Square
Treatment	404.93	2	202.47
Error	82755.06	28	2955.54
Total	83160.00	30	

F-Statistic = .069

Throughput

Sample Means:		
FIFO	590.80	per year
Batch	593.68	" "
Priority	588.58	" "

ANOVA	Sum of Squares	Degrees of Freedom	Mean Square
Treatment	706.47	2	353.24
Error	34044.19	28	1215.86
Total	34750.67	30	

F-Statistic = .291

Utilization

Sample Means:	
FIFO	12.31%
Batch	11.95%
Priority	12.18%

ANOVA	Sum of Squares	Degrees of Freedom	Mean Square
Treatment	2.02	2	1.01
Error	29.06	28	1.04
Total	31.08	30	

F-Statistic = .975

distributions are different (the ATE queuing time is approximately normal). Intuitively however, lower MTBA items that appear many times in the repair process have a higher probability of being subject to a long spares delay. Further arrivals quickly exhaust the spares stocks and backorders occur.

Another expected result was the high percentage of backorders occuring. Approximately thirty-four percent of jobs arriving caused a new backorder. Consequently, most of the scheduling was based on the clearing of backorders and the other scheduling methods may have not had the opportunity to influence the system. Collection of the number of backorders per type of component in a period confirmed that about ten of the low MTBA types were responsible for over eighty percent of backorders. Most of these moved in and out of a backorder situations, reaching a maximum of between two or four backorders in a period. However, two components (known problems) were in a consistent backorder status and often reached backorder levels in the order of ten to twelve. It was possible that these components were masking any benefits that might be obtained from the revised scheduling techniques.

To investigate this possibility, the initial stock levels for these two components was increased until their backorders levels were similar to those of the other components. This naturally resulted in a lower number of backorders per cycle, but there was still no difference found between any of the scheduling methods. Also, even though the mean number of backorders was reduced, the percentage of jobs arriving that resulted in a backorder was only reduced from thirty-four to thirty-one percent and the scheduling would still have been dominated by the backorders.

More sweeping increases in the stock levels of components could have been made to attempt to reduce the backorder percentage further. In practice, this would be expensive. A better approach would be to attempt to reduce the spares delay time, either by improvement of the supply system, or by procurement of additional consumable spares. Analysis of whether either of these suggestions is feasible is beyond the scope of this research. However, to determine whether further research seemed warranted, the mean spares delay time was reduced by twenty-five percent and the model was run again with each of the scheduling methods. This reduced the percentage of jobs arriving that resulted in a backorder to twenty-four percent, but there was still no significant difference found between any of the scheduling methods. The calculated F-statistics had increased slightly, for example the calculated statistic for backorders was 0.23, but were still well below the critical statistic of 3.32. Thus there was still a high degree of confidence that the different scheduling methods had no effect on the output of the ATE system.

Conclusions

The study showed that the 492SQN ATE workshop efficiency was unlikely to be improved by changes in the scheduling methods. The high number of backorders occurring in the system dictates the scheduling priority, leaving little opportunity for any other method to have any influence. Considerable investment in either spares or supply system inprovements (probably both) would have to be made before the scheduling method became significant.

Recommendations

There is little point in continuing with further research into scheduling methods for the 492SQN system as the problem lies more with the backorder levels, and this should be addressed first. However, it is still possible that a system with less backorders may be able to benefit from the revised scheduling methods proposed in this study.

Appendix A: Simulation Listing

```
GEN,D.A.HIGGINS,ATE SIMULATION,4/3/85,,NO,NO,,,,,;
LIMITS,5,10,500;
;
;
;RECORD,TNOW,TIME,0,P,50,0,6000;
;VAR,XX(96),*,NO IN SYSTEM;
;VAR,XX(95),Q,NO IN Q5;
;
;TIME UNIT IS 1HR
;
NETWORK;
;
        RESOURCE/ATE1(0),1;
        RESOURCE/ATE2(0),2;
;
;
;UNSERVICEABLE LRU ARRIVALS
;
QUE     GOON;
        COLCT(3),ALL,NEW LRUS;
        ASSIGN,XX(95)=NNQ(5);
        ASSIGN,XX(96)=XX(96)+1;           INCREMENT # LRUS IN SYSTEM
        ASSIGN,II=ATRIB(1);
        ACT,,XX(II).GE.0,CO1;
        ACT,,XX(II).LT.0;
        ASSIGN,XX(97)=XX(97)+1;           INCREMENT # BACKORDERS
CO1     GOON;
        ACT,,NNRSC(ATE1).NE.1,CO;
        ACT,,NNRSC(ATE1).EQ.1,AT1;
CO      GOON;
        ACT,,NNRSC(ATE2).NE.1,Q;
        ACT,,NNRSC(ATE2).EQ.1,AT2;
Q       QUEUE(5);                         US LRUS
;
;******ATE #1******
AT1     AWAIT(1/1),ATE1,1;
        ASSIGN,ATRIB(9)=TNOW;
        ACT/1,UNFRM(0.133,0.2);           SELECT NEXT LRU (8-12 MINS)
        GOON,1;
        ACT,0.083,ATRIB(1).EQ.XX(98),T1;  SAME LRU TYPE, 5 MIN CHANGEOVER
        ACT,,ATRIB(1).NE.XX(98);
        ASSIGN,XX(98)=ATRIB(1);
        GOON;
        ACT,UNFRM(0.083,0.167);           TEAR DOWN TIME (5- 10 MIN)
        GOON;
        ACT,UNFRM(0.167,0.417);           SET UP TIME (10-25 MIN)
;
```

```
T1      GOON;
        ACT,ATRIB(2);                         FAILS ONLY RUN
        GOON;
        ACT,,ATRIB(5).EQ.0,F1;
        ACT,,ATRIB(5).NE.0;
;
R1      GOON;                                 POST REPAIR CHECK
        ACT,,ATRIB(5).EQ.1,TM1;               PASSED TEST AFTER REPAIR
        ACT,,ATRIB(5).NE.1,D1;                FAILED TEST AFTER REPAIR
;
F1      GOON;                                 FIRST TEST
        ACT,,0.94,D1;                         FIRST TIME THRU
        ACT,,0.06,TM1;                        NO FAULT FOUND
;
D1      GOON;                                 FAILURES FOUND
        ACT,UNFRM(ATRIB(6),ATRIB(7));         DIAGNOSTIC RUN
        GOON,1;
        ACT,0.083;                            PAPERWORK (5 MIN)
        COLCT(4),INT(9),TIME ON ATE1;
        EVENT,1,1;
        FREE,ATE1;
        ACT,,ATRIB(5).EQ.0.5,REP2;            GO BACK FOR 2ND REPAIR
        ACT,,ATRIB(5).NE.0.5
        GOON;
        ACT,,0.23,REP1;                       ONE REPAIR CYCLE
        ACT,,0.77,REP2;                       TWO REPAIR CYCLES
;
TM1     GOON,1;
        ACT,0.083;                            5 MIN PAPERWORK
        EVENT,1,1;
        FREE,ATE1;
        ACT,,,TERM;
;
;******ATE #2******
;
AT2     AWAIT(2/1),ATE2,1;
        .
        . (same as ATE1)
        .
        EVENT,2,1;
        FREE,ATE2;
        ACT,,,TERM;
;**************************
;
;SERVICEABLE LRUS LEAVING
TERM    COLCT(1),INT(10),AVE TAT;
        COLCT(2),XX(97),NO BACKORDERS;
        ASSIGN,XX(96)=XX(96)-1;                 DECREMENT # LRUS IN SYSTEM
        ASSIGN,XX(95)=NNQ(5);
        ASSIGN,II=ATRIB(1);
        ASSIGN,XX(II)=XX(II)+1;                 INCREMENT STOCK LEVEL
        TERM;
;
```

```
;******REPAIRS******
;
REP1    GOON;
        ASSIGN,ATRIB(5)=1.0;                         REPAIRS COMPLETE
        ACT/3,GAMA(92.75,0.4705),,Q4;                SPARES AND REPAIR DELAY
;
REP2    GOON;
        ACT,,ATRIB(5).NE.0.0,DL2;
        ACT,,ATRIB(5).EQ.0.0;
        ASSIGN,ATRIB(8)=GAMA(92.75,0.4705);
DL2     GOON;
        ASSIGN,ATRIB(5)=ATRIB(5)+0.5;
        ACT/4,ATRIB(8)/2,,Q4;                        1/2 SPARES AND REPAIR DELAY
;
Q4      QUEUE(4);                                    REPAIRED LRUS QUEUE
;
;
;******SHIFTS ON/OFF ******
        CREATE,,0.001,,1,1;
        ASSIGN,XX(100)=0;
BACK    GOON;
        ACT,,,ST1;
        ACT,,,ST2;
;
ST1     ALTER,ATE1/1;
        ASSIGN,ATRIB(1)=TNOW;
        ACT,4.6;
        ALTER,ATE1/-1;
WT1     GOON,1;
        ACT,.02,NNRSC(ATE1).NE.0,WT1;
        ACT,,NNRSC(ATE1).EQ.0,ENDAY;
;
ST2     ALTER,ATE2/1;
        ASSIGN,ATRIB(1)=TNOW;
        ACT,4.6;
        ALTER,ATE2/-1;
WT2     GOON,1;
        ACT,.02,NNRSC(ATE2).NE.0,WT2;
        ACT,,NNRSC(ATE2).EQ.0,ENDAY;
;
ENDAY   COLCT(6),INT(1),ATE DAY;
        ACCUM,2,2,,1;                                WAIT TILL BOTH ATES FIN
        ASSIGN,ATRIB(2)=ATRIB(1)+24-TNOW;
        ACT,ATRIB(2);                                REMAINDER OF DAY
;
;****WARNING - REMOVE NEXT STATEMENT FOR FIFO RUNS
        EVENT,3,1;                                   RE-CALC PRIORITIES
        ASSIGN,XX(100)=XX(100)+1;
        ACT,,XX(100).LE.5,BACK;
        ACT/5,2.25*24,XX(100).GT.5;                  WEEKEND = 2.25 DAYS
        ASSIGN,XX(100)=0;
        ACT,,,BACK;
;
```

```
;********INITIAL STOCK LEVELS*******
;
;XX(1)-(94) = STOCK LEVELS
;XX(95)     = NNQ(5)
;XX(96)     = # LRUS IN SYSTEM
;XX(97)     = #BACKORDERS
;XX(98)     = LAST LRU TYPE THRU ATE1
;XX(99)     = LAST LRU TYPE THRU ATE2
;XX(100)    = DAYS OF WEEK COUNT
;SS(1)      = POINTER FOR NEXT BACKORDER SEARCH
;
       CREATE;
       ASSIGN,XX(1)=9,
              XX(2)=2,
              .
              .
              .
              XX(94)=1,
              XX(96)=0,
              XX(97)=0;
       TERM;
;
;******LRU CHARACTERISTICS******
;
;AT(1)=LRU TYPE
;AT(2)=FAILS RUN TIME
;AT(3)=MTBA
;AT(4)=PRIORITY
;AT(5)=JUST FAILED FLAG
;AT(6)=DIAG RUN LOWER LIMIT
;AT(7)=DIAG RUN UPPER LIMIT
;AT(8)=SPARES DELAY TIME
;AT(9)=TIME ON ATE
;AT(10)=TURN AROUND TIME
;
;LRU #1
       CREATE,EXPON(431.5),,10;
       ASSIGN,ATRIB(1)=1,
              II=ATRIB(1),
              XX(II)=XX(II)-1,
              ATRIB(2)=0.033,
              ATRIB(3)=92.95,
              ATRIB(4)=(XX(II)+1)/ATRIB(3),
              ATRIB(5)=0,
              ATRIB(6)=3.0*ATRIB(2),
              ATRIB(7)=4.0*ATRIB(2);
      ACT,,,QUE;
;LRU #2
       CREATE,EXPON(3172.00),,10;
       .
       . (94 component types)
       .
```

Appendix B: Fortran Routines

Main Routine

```
      PROGRAM MAIN
      DIMENSION NSET(30000)
      COMMON QSET(30000)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,
     *MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),
     *SSL(100),TNEXT,TNOW,XX(100),NRANK,KEW,EN,TEMP(100)
      EQUIVALENCE (NSET(1),QSET(1))
      SS(1)=0
      NCRDR=5
      NPRNT=6
      NTAPE=7
      NNSET=30000
      CALL SLAM
      STOP
      END
C************************************************************************
*
      SUBROUTINE EVENT(I)

        (see subroutines for each scheduling algorithm)
```

Backorder/Zero Stock/First-In-First-Out Subroutine

```
      SUBROUTINE EVENT(I)
      DIMENSION NSET(30000)
      COMMON QSET(30000)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,
     *MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),
     *SSL(100),TNEXT,TNOW,XX(100),NRANK,KEW,EN,TEMP(100)
      EQUIVALENCE (NSET(1),QSET(1))
      IF(NNQ(5).EQ.0)RETURN
C
C*****LOOK FOR A BACKORDER ITEM
C
      NRANK=0
C*****START SEARCH WHERE LEFT OFF LAST TIME
      EN=SS(1)
   10 EN=EN+1
      IF(EN.GT.94)EN=1
      IF(XX(EN).LT.0)THEN
        KEW=4
        NRANK=NFIND(1,4,1,0,EN,0.0)
        IF(NRANK.EQ.0)THEN
          KEW=5
          NRANK=NFIND(1,5,1,0,EN,0.0)
        ENDIF
      ENDIF
      IF(NRANK.NE.0) GO TO 99
      IF(EN.EQ.SS(1)) GO TO 40
      GO TO 10
C
C*****LOOK FOR A ZERO STOCK ITEM
C
   40 EN=EN+1
      IF(EN.GT.94)EN=1
      IF(XX(EN).EQ.0)THEN
        KEW=4
        NRANK=NFIND(1,4,1,0,EN,0.0)
        IF(NRANK.EQ.0)THEN
          KEW=5
          NRANK=NFIND(1,5,1,0,EN,0.0)
        ENDIF
      ENDIF
      IF(NRANK.NE.0) GO TO 99
      IF(EN.EQ.SS(1)) GO TO 50
      GO TO 40
```

```
C*****TAKE FIRST ITEM IN Q4 OR Q5
C
   50 IF(NRANK.EQ.0)THEN
        NRANK=1
        KEW=4
        IF(NNQ(4).EQ.0)KEW=5
      ENDIF
C
   99 SS(1)=EN
C
C*****TRANSFER LRU TO ATE
C
      GOTO(100,200),I
  100 CALL RMOVE (NRANK,KEW,TEMP)
      CALL FILEM (1,TEMP)
      RETURN
  200 CALL RMOVE (NRANK,KEW,TEMP)
      CALL FILEM (2,TEMP)
      RETURN
      END
```

Batch/Backorder/Zero Stock/First-In-First-Out Subroutine

```
      SUBROUTINE EVENT(I)
      DIMENSION NSET(30000)
      COMMON QSET(30000)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,
     *MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),
     *SSL(100),TNEXT,TNOW,XX(100),NRANK,KEW,EN,TEMP(100)
      EQUIVALENCE (NSET(1),QSET(1))
      IF(NNQ(5).EQ.0 .AND. NNQ(4).EQ.0)RETURN
C
C*****LOOK FOR AN LRU OF SAME TYPE
      GO TO (3,4),I
    3 EN=XX(98)
      GO TO 5
    4 EN=XX(99)
    5 NRANK=NFIND(1,4,1,0,EN,0.0)
      KEW=4
      IF(NRANK.NE.0)GO TO 99
      NRANK=NFIND(1,5,1,0,EN,0.0)
      KEW=5
      IF(NRANK.NE.0)GO TO 99
C
C*****LOOK FOR A BACKORDER ITEM
C
      NRANK=0
      EN=SS(1)
   10 EN=EN+1
      IF(EN.GT.94)EN=1
      IF(XX(EN).LT.0)THEN
        KEW=4
        NRANK=NFIND(1,4,1,0,EN,0.0)
        IF(NRANK.EQ.0)THEN
          KEW=5
          NRANK=NFIND(1,5,1,0,EN,0.0)
        ENDIF
      ENDIF
      IF(NRANK.NE.0) GO TO 95
      IF(EN.EQ.SS(1)) GO TO 40
      GO TO 10
C
C*****LOOK FOR A ZERO STOCK ITEM
C
   40 EN=EN+1
      IF(EN.GT.94)EN=1
      IF(XX(EN).EQ.0)THEN
        KEW=4
        NRANK=NFIND(1,4,1,0,EN,0.0)
        IF(NRANK.EQ.0)THEN
```

```
            KEW=5
            NRANK=NFIND(1,5,1,0,EN,0.0)
          ENDIF
        ENDIF
        IF(NRANK.NE.0) GO TO 95
        IF(EN.EQ.SS(1)) GO TO 50
        GO TO 40
C
C*****TAKE FIRST ITEM IN Q4 OR Q5
C
   50 IF(NRANK.EQ.0)THEN
          NRANK=1
          KEW=4
          IF(NNQ(4).EQ.0)KEW=5
        ENDIF
C
   95 SS(1)=EN
C
C*****TRANSFER LRU TO ATE
C
   99 GOTO(100,200),I
  100 CALL RMOVE (NRANK,KEW,TEMP)
      CALL FILEM (1,TEMP)
      RETURN
  200 CALL RMOVE (NRANK,KEW,TEMP)
      CALL FILEM (2,TEMP)
      RETURN
      END
```

Backorder/Priority Subroutine

```
      SUBROUTINE EVENT(I)
      DIMENSION NSET(30000)
      COMMON QSET(30000)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,
     *MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),
     *SSL(100),TNEXT,TNOW,XX(100),NRANK,KEW,EN,TEMP(100)
      EQUIVALENCE (NSET(1),QSET(1))
C
      GOTO (1,1,500),I
C
    1 IF(NNQ(5).EQ.0 .AND. NNQ(4).EQ.0)RETURN
C
C*****LOOK FOR A BACKORDER ITEM
C
      NRANK=0
      EN=SS(1)
   10 EN=EN+1
      IF(EN.GT.94.0)EN=1.0
      IF(XX(EN).LT.0.0)THEN
        KEW=4
        NRANK=NFIND(1,4,1,0,EN,0.0)
        IF(NRANK.EQ.0)THEN
          KEW=5
          NRANK=NFIND(1,5,1,0,EN,0.0)
        ENDIF
      ENDIF
      IF(NRANK.NE.0) THEN
        SS(1)=EN
        GO TO 99
      ENDIF
      IF(EN.EQ.SS(1)) GO TO 50
      GO TO 10
C
C*****SELECT HIGHEST PRIORITY ITEM
C
   50 NRANK4=NFIND(1,4,4,-1,100.0,0.0)
      NRANK5=NFIND(1,5,4,-1,100.0,0.0)
      IF(NRANK4.EQ.0)THEN
        KEW=5
        NRANK=NRANK5
        GOTO99
      ENDIF
      IF(NRANK5.EQ.0)THEN
        KEW=4
        NRANK=NRANK4
        GOTO99
      ENDIF
```

```
      CALL COPY(NRANK4,4,TEMP)
      PRI4=TEMP(4)
      CALL COPY(NRANK5,5,TEMP)
      PRI5=TEMP(4)
      IF(PRI4.GE.PRI5)THEN
        KEW=4
        NRANK=NRANK4
        CALL COPY(NRANK4,4,TEMP)
      ELSE
        KEW=5
        NRANK=NRANK5
      ENDIF
C
C*****TRANSFER LRU TO ATE
C
   99 GOTO(100,200),I
  100 CALL RMOVE (NRANK,KEW,TEMP)
      CALL FILEM (1,TEMP)
      RETURN
  200 CALL RMOVE (NRANK,KEW,TEMP)
      CALL FILEM (2,TEMP)
      RETURN
C
C*****CALCULATE PRIORITIES
C
  500 IF (NNQ(4).EQ.0)GO TO 600
  550 CALL RMOVE (1,4,TEMP)
C     PRIORITY=STOCK REMAINING+1/MTBA
      TEMP(4)=(XX(TEMP(1))+1)/TEMP(3)
      CALL FILEM (4,TEMP)
      IF(NNQ(4).NE.0)GO TO 550
C
  600 IF (NNQ(5).EQ.0)RETURN
  650 CALL RMOVE (1,5,TEMP)
C     PRIORITY=STOCK REMAINING+1/MTBA
      TEMP(4)=(XX(TEMP(1))+1)/TEMP(3)
      CALL FILEM (5,TEMP)
      IF (NNQ(5).NE.0)GO TO 650
      RETURN

      END
```

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This ~~study~~ investigated the effects of different scheduling methods on the throughput of Automatic Test Equipment. The types of scheduling considered were first-in-first-out (FIFO), a modified FIFO where all components of the same type were processed in a batch, and a priority scheduling based on determination of the expected time to the next backorder, as predicted by renewal theory, with priority given to the component with the shortest expected time to a backorder.

The study was accomplished by constructing a simulation model of the Royal Australian Air Force ATE workshop at 492SQN in South Australia. The repair process was modelled from the time a component became unserviceable to the time it became serviceable again. The arrival process for components was assumed to be Poisson. The ATE testing of components was modelled in detail, but the physical repair and any spares delay were represented by a gamma distribution.

The study showed that, for this workshop, the different scheduling methods had little effect because the repair time and spares delay were relatively large, compared to the ATE testing time, and these were the controlling influences in the system.

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