TURBINE ENGINE MAINTENANCE MANPOWER AND FACILITY MODEL

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ABSTRACT

GPSS/360 was used to model manpower allocation in the Turbine Engine Maintenance Process. The purpose was to evaluate alternate proposals for allocation of manpower. Forecasted workloads of engines were processed against these proposals. Simulation outputs included engine production times and quantities of engines produced. Also included are manpower and facility utilization outputs. Appraisal of outputs by management aided in selection of a manpower allocation plan.

INTRODUCTION

At year ending 1971 United Air Lines will be operating 384 jet aircraft servicing regular schedules for 114 cities from Hawaii to New York and Vancouver, British Columbia to Miami. The aircraft types include the Boeing 747, 720, 727, 737, and the Douglas DC8 and DC10.

Major maintenance, engineering, modification, and parts supply of both the airframe and power plant are accomplished at the United Air Lines Maintenance Base at San Francisco International Airport. This facility provides the mechanics, tools, and skills for what has often been described as the finest, most modern and complete airline maintenance facility in the world. In addition, United Air Lines provides air frame and engine maintenance service for other airlines as well as maintenance of turbine engines used in various industrial applications. Well equipped machine, sheet metal and electrical shops are available for customers in non-airline fields.

TURBINE ENGINE MAINTENANCE

Turbine engines are repaired and maintained in one of the world's largest specially designed buildings that, by the end of 1971, will be approximately 900,000 square feet. The Turbine Engine Maintenance Department has a staff of approximately 2,100 mechanics and support personnel. This department produces approximately one-hundred and sixty engines per month which are used to replace engines removed from aircraft due for inspection or maintenance.

A jet, or turbine engine, as it is commonly called in the industry, consists of two major sections. The cold or front section guides air into the engine and compresses it and the hot or rear section is the gas generator which turns the turbines which in turn drives the compressors. Because of this relationship, complete disassembly is required if the cold section must be removed (Figure 1).

Turbine engine repair requirements are usually diagnosed through inspection or test cell runs. Some engines are modified to improve performance. Once the repair sequence is determined, minor or major disassembly of the engine is accomplished in a work area commonly called a repair stall. Depending on the nature of the maintenance required, many different operations might be performed, each of which requires a different range of manhours to perform. Three Major Repair Categories referenced in the model indicate the extent of disassembly required. They are:

1. Minor Repair
   Quick turnaround. Minor repairs requiring minimum disassembly.
2. Cold Section
   Major repair. Most extensive disassembly.
3. Hot Section
   Major disassembly and intermediate disassembly.

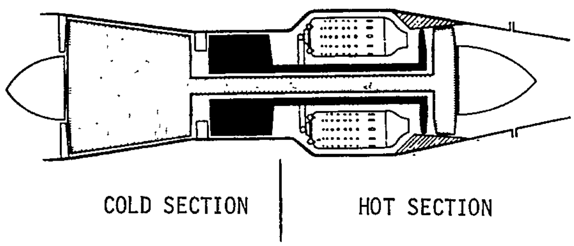
There are fourteen sub work elements which an engine could progress through in the Cold Section and Hot Section categories. Only one element of work is usually involved in the Minor Repair category. Crews ranging from two to four mechanics are assigned, based on the category and element of work. Mechanics are assigned to crews from a manpower pool of people available for work on the current shift. Manpower pools vary based on absenteeism, skills, and other work priorities.

Mechanics are usually proficient in working more than one engine type; however, manpower pools generally are grouped by engine type. These engine types are listed below:

Engine	Used on Type of Aircraft
Pratt & Whitney JT8D	Boeing 727 and 737
Pratt & Whitney JT3 C-7	Boeing 720
Pratt & Whitney JT4A and JT3D	Douglas DC8
Pratt & Whitney JT9D	Boeing 747
General Electric CF6	Douglas DC10

Stall areas are physically grouped by engine type within the Turbine Engine Maintenance Building. These areas represent a common area of supervision.

A series of priorities have been established for the purpose of assigning manpower to engines from the available pool. Assignment of manpower to an engine is dependent on which element of disassembly or reassembly the engine is in. Manpower will be assigned to all engines in the Minor Repair Category or in one of the disassembly elements first, minor assembly elements second, and then major assembly elements. Normally Minor Repair engines can be repaired within twenty-four hours, Cold Section or Hot Section repairs usually require from ten to eighteen work days.



CROSS SECTION OF TURBINE ENGINE
FIGURE 1

STATEMENT OF THE PROBLEM

Turbine engines at United range in value from a quarter of a million to over one million dollars. United owns one-hundred and sixty spare engines. A pool of serviceable engines must be provided to replace engines removed for maintenance from aircraft so the aircraft is not held out of service.

An engine may take an average of fourteen work days or forty-two shifts to complete. Exactly how to assign manpower during this period is of concern to the Production Planning Manager.

The original intent of this modeling effort was to provide a general purpose tool for management to evaulate their ideas. At the time they indicated they wanted to look into new approaches for leveling engine inputs and planning facilities, manpower and inventories. The major challenge is to provide an adequate supply of spare engines and get maximum utilization of personnel. Engine cycle times must also be minimized so that the cost of spare engine fleets are not excessive. This goal must be accomplished in light of varying engine inputs with variations in work content.

Early in 1971 Management was faced with many production questions. What are the effects on cycle time if we eliminate a third shift? How can we reallocate personnel to meet increased workloads to avoid increasing manpower pools? With limited resources, what crew size combinations seem to contribute to the greatest productivity?

These questions became even more difficult to analyze when treated in a dynamic environment, i.e., fluctuations in work loads, attendance, and job work content. Simulation provides a relatively easy way to express all these variables and observe the results.

Many of the past approaches to allocating manpower have been primarily tested through trial and error. Obviously, this technique becomes more costly as the operating environment changes more rapidly. Therefore, management made a request to determine if some of the operating proposals under consideration could be modeled and simulated so predicted results could be reviewed to aid in selection of a manpower allocation plan.

SELECTION OF A SIMULATION LANGUAGE

In terms of evaluating use of a programming language the authors only had experience with using FORTRAN and GPSS for simulation purposes. It was obvious that the programming time would be reduced considerably by using GPSS.[1] The project emphasis was on developing a model and reaching a decision as soon as possible; therefore, the obvious selection was GPSS. United Air Lines/Maintenance Base has both the IBM 360/Model 65 and Model 50. The Model 65 was selected because of faster processing times.

The simulation model developed has 139 blocks. This model was allocated 150K of core and had a run time of less than five minutes on the Model 65. The unit of time used was an hour and run durations of one to four years of simulated time were employed. Two man-months were required for the development and programming of this model.

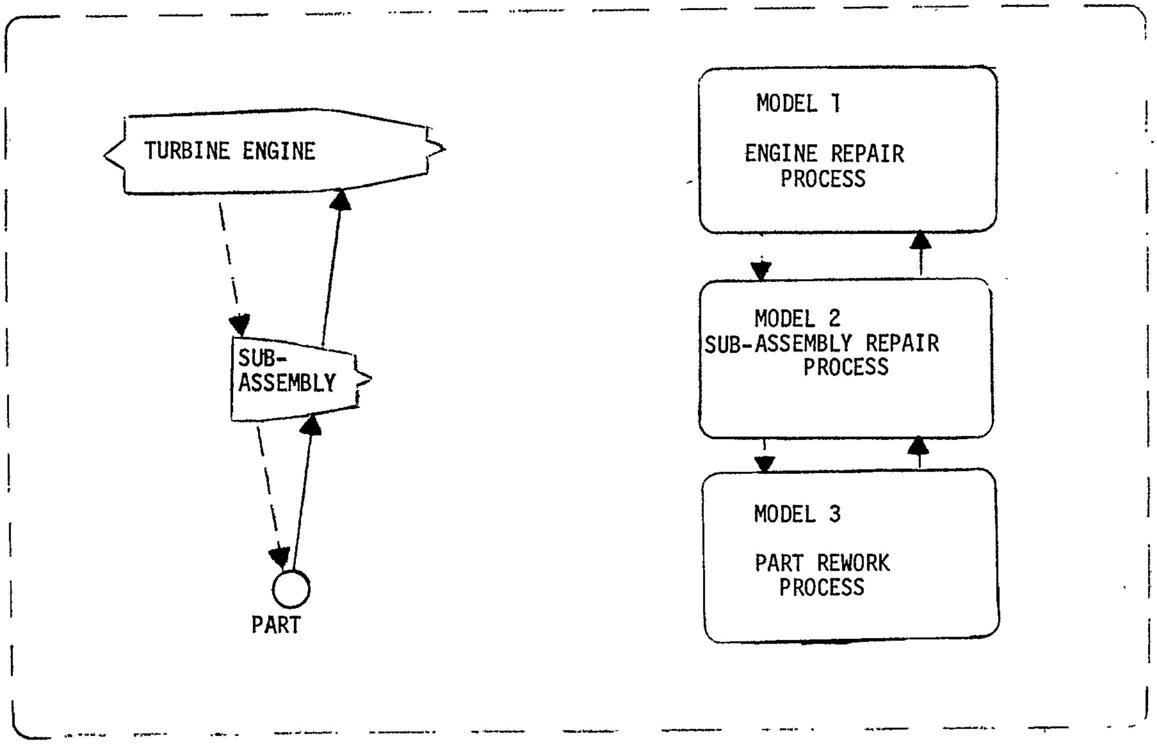
The transaction oriented GPSS system was ideally suited for the modeling we desired. The ability of GPSS to easily mimic the actual engine maintenance process by combining random quantities of different random variables made it possible to analyze this otherwise very complex process.

INITIAL APPROACH TO MODEL DEVELOPMENT

In initially designing the framework for the engine maintenance model the usual dilemma of model sizing was encountered. The typical question to be answered was, "How can we break down the model into enough detail so it represents the real engine maintenance function, but it is not so detailed that it is beyond manageable core limits or economic computer run times?" The approach used was to break down into just enough detail all of the important resources, i.e., manpower, facilities, and material so that meaningful relationships between them could be measured and economic adjustments made. The detail that we finally deemed essential for this model includes:

INPUTS

1. Frequency of engines removed requiring work.



MODULAR SIMULATION PLAN
TURBINE ENGINE REPAIR & REWORK PROCESS
FIGURE 2

2. Frequency of rework required.
   a. Minor Repair
   b. Cold Section
   c. Hot Section
3. Hours required to perform each task.
4. Manpower available to assign to tasks.
5. Facilities available to assign to engine workplace.
6. Frequency of down time due to lack of parts.

PROCESSING

1. Assignment of new engines to shifts.
2. Allocating manpower and facilities based on priority of work.
3. Crew requirements for tasks.
4. Decision timing - re-evaluation periods.

OUTPUTS

1. Manpower utilization.
2. Engine transit times.
3. Engine production.
4. Facility utilization.

OVERALL MODELING PLAN

Although the use of the model as outlined in this writing may seem somewhat limited in terms of the total engine repair process, it is really only one piece of the plan. Originally the writers were considering simulating one all encompassing model that would simulate the entire engine repair process including related sub-assembly repair and part replacement inventory. This approach, for reasons previously mentioned, was abandoned for a modular approach. Development of separate models of relevant modules of the engine repair process are illustrated in Figure 2.

Through use of this modular technique we hope to shorten overall programming time and make timely decisions. Through coordinating the modules we still will be able to retain an advantage of having a system model.

Models 1, 2, and 3 represent all activities required to rework and repair turbine engines. When sub-assemblies are removed as part of Model 1 they are sent to the sub-assembly repair area (Model 2). As subassemblies are broken down to units or parts they in turn are sent to rework shops for repair. (Model 3) Model 1 is the subject of this paper. The inter-relationship is fairly obvious, in that, the engine and sub-assemblies must wait for unit parts to be repaired or a pool of new or repaired parts must be available to supply these demands.

MODEL LOGIC FLOW

In developing the model requirement, the next step was to outline the general logic flow. In other words, describe the relationship of engine model resources. This general relationship is described in Figure 3.

SELECTION OF INPUT DATA

United Air Lines largest spare engine fleet is the Pratt-Whitney JT8D engine which is used on both the Boeing 727 and 737 aircraft. For this reason, it was decided to use this engine for our initial model for testing and verification purposes. Indications were that if we could get a successful test with the JT8D with some modification, we could use the model for other engine types. Essentially, the logic for one engine type is similar to another.

COLLECTION OF INPUT DATA

Actual daily inputs of JT8D engines were recorded for February through August 1969. From these records a GPSS daily engine input function was developed to express this distribution. In addition, a function was developed to express a distribution by Major Repair Category. This was identified for incoming transactions in a Major Repair Category parameter.

Next, a routine was developed to allocate new engines equally to each shift. This was expressed through a GPSS function. The purpose of this rule is to balance the new engine work load between the shifts.

Actual crew assignment rules for this 1969 period were used and from these a matrix savevalue was developed so that specific crew assignments could be specified for given elementsof work.

Crew assignments presently vary between two to four people, depending on the element of work within the Major Repair Category.

Next, an hours-to-be-worked matrix was developed. For each work sequence within a Major Repair Category, actual hours worked were taken from job cards. There was a significant variation in hours-to-be worked within an element of work. This meant that there had to be an expression for this variance within each cell of the matrix savevalue. The technique used is one that has been referred to as nesting functions. Function numbers were inserted in the cell representing hours-to-be-worked for the element. Each function number represented a range of hours. In assigning work to a new engine, this transaction will reference the nested function number which through the random number generator selects hours-to-be-worked from the range and assigns it to the hours-to-be-worked parameter.

PROCESSING THE ENGINES

Engines are generated daily as input into the shop repair process. Engine starts are assigned to shifts. The program allocates hours-to-be-worked to each transaction. These engine transactions are then processed into work positions or stalls. Thirty-six stalls were allocated for the JT8D.

At the beginning of each shift, manpower is allocated to each engine in-process based on the priority of work element that the engine is currently in. Through use of a repair crew matrix savevalue, the crew size is allocated to the engine and the available manpower pool is reduced by the

GENERAL ENGINE MODEL FLOW

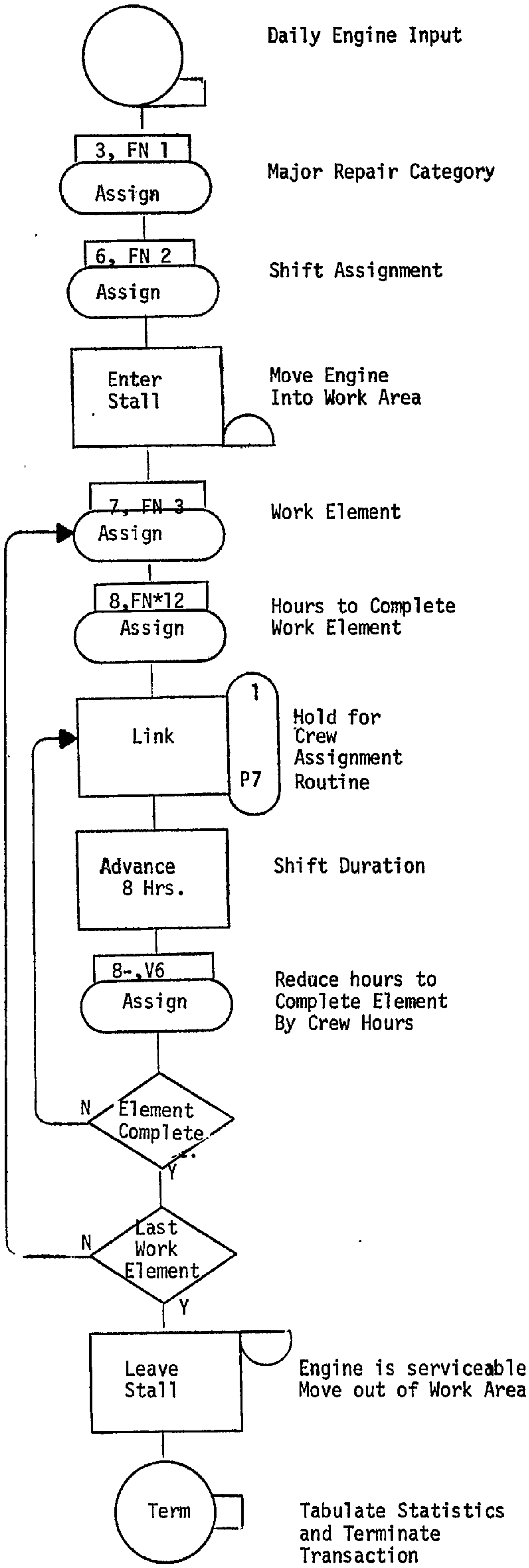
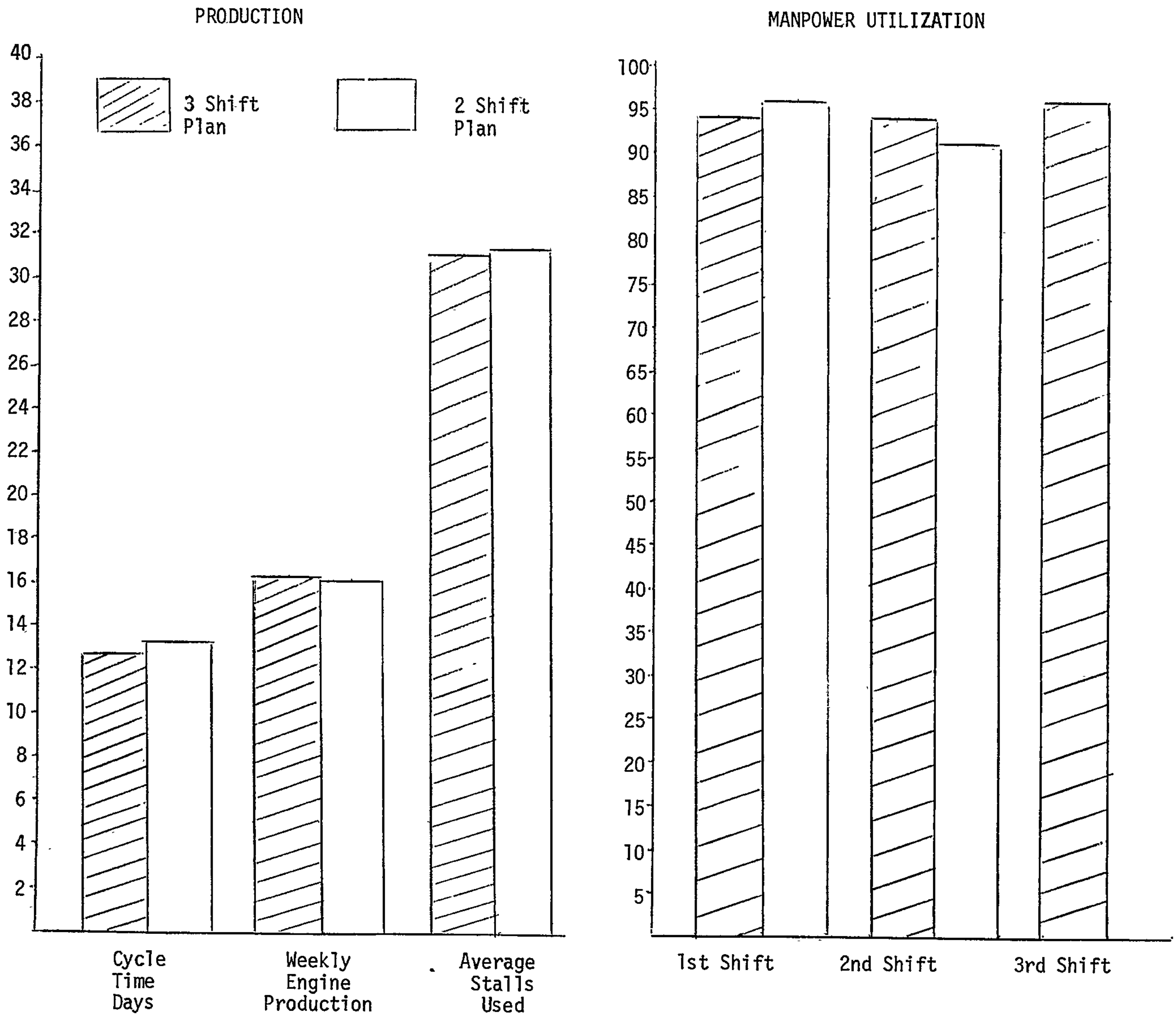


FIGURE 3



JT8D Two vs. Three Shift Production and Manpower Utilization

Figure 4

number of members of that crew. This process continues until all of the men have been assigned to engines in-process or until the manpower pool is depleted.

During the shift the total available crew hours for each engine are subtracted from the hours-to-be-worked parameter and a new balance of hours to be worked is stored in this transaction parameter. This continues for each shift until the engine has completed all the steps of disassembly and assembly.

VERIFICATION

The simulated results of the JT8D engine repair data for February through August of 1969 were carefully observed. These results were compared with the actual cycle times, weekly engine production and facility utilization figures for the same period. Initial runs resulted in significant deviations and were traced to programming logic errors. When corrected, the simulated model results did not deviate from the actual history by more than plus or minus five percent in these three categories.

This model could probably have been refined even further; however, this would have required considerably more programming time. It was managements' judgement that more would be gained by a timely decision at this point than would be gained by further refinement of the model.

SIMULATION OF TWO VS THREE SHIFT PLANS

Due to a drop off in the demand for aircraft seats linked to the economy decline in late 1970 and early 1971 a decision was made to cut back the number of flights. The fewer flights would require fewer engine maintenance repairs than originally

FIGURE 5

Crew Allocation Plans - Simulated Outputs

Plan	Crew Sizing	Engine Cycle Days	Weekly Engine Production	M/P Utilization	
				Days	Swing
A	2 Man Crew	15.3	11.5	75	78
B	2 & 3 Man Crew	13.3	12.3	81	86
C	3 Man Crew	12.8	12.6	91	90
D	3 & 4 Man Crew	13.4	12.3	95	94
E	4 Man Crew	16.4	11.0	97	92

NOTE: Half the elements worked through Plan B are assigned 2 man crews and half are assigned 3 man crews. Half the elements worked through Plan D are assigned 3 man crews and half are assigned 4 man crews.

forecast for 1971. This prompted management to reconsider their existing three shift operation for repairing the JT8D, JT3D, JT4 and JT3C-7 turbine engines.

The Industrial Engineering department was asked to determine the economic effects of re-allocating the existing third shift manpower to the first and second shifts. The preliminary indications in March 1971 were that managements' proposed two shift plan would offer a savings of $210,000 for the remainder of 1971. This savings could be realized through the need for fewer productive support people for third shift; not having to pay a premium shift differential pay; and improvements in productivity.

Although management felt this savings was significant they still were concerned about the ability of the two-shift operation to maintain the production required to support the airline with an adequate supply of spare serviceable engines.

In that this simulation model was just completed and tested for the JT8D engines, the authors were asked to simulate the input criteria for 1971 for the two and three shift plans. Basically, the only variation in inputs in the two shift plan was that manpower previously assigned to third shift was reallocated equally to the first and second shifts. All other inputs, engine volumes, stalls available, etc., remained the same for the two shift plan. This input data was keypunched and processed into the JT8D model. Runs were made for a twelve month period. The output for the JT8D is illustrated in Figure 4.

These outputs were presented to management. The cycle time, engine production and manpower utilization figures indicated that production levels could be maintained and no losses due to shortages of engines would result. A decision was made to use a modified two shift plan. This plan retained a third shift skeleton work crew for potentially critical areas and would still yield a savings of $161,000 by year end.

Further analysis could probably have yielded further manpower saving with the two shift structure; however, management requested a quick decision on the plan at this point to take advantage of the savings.

SIMULATION OF ALTERNATE CREW SIZING PLANS

Following the decision to proceed with the two shift plan the designers of the model were asked to look into possible re-arrangement of crew sizes. Crews are allocated to engines based on the priority of the engine and the number assigned to the crew will depend on the specific disassembly or assembly tasks to be performed. Various combinations of crews can be assigned to tasks; however, the object is to minimize cycle times and engine production times with a limited pool of available mechanics.

Five options were being considered for evaluation. These plans are illustrated in Figure 5.

The authors were asked to simulate these five plans for the JT8D (727) engine to determine the effects on engine production and manpower utilization. For each of these five plans the average daily JT8D engine input was forecast at an average of 2.7 engines per day with thirty stall positions available to work engines in. The manpower available averaged sixty-two men on days and fifty-six men assigned to swing shift for each plan.

United management reviewed these outputs and agreement was reached that Plan C would offer the lowest cycle time as well as improved engine production. Also, the manpower utilization appears to be acceptable.

While the Plans A and B had lower manpower utilization it appears the cycle times are higher due to spreading the manpower too thin. On the other hand, the higher manpower utilization reflected in Plans D and E resulted in higher engine cycle times, and lower production due to depleting the manpower pools too soon resulting in not working all engines available.

AUDIT OF TWO SHIFT DECISION

In August 1971 a review was made of the Engine Repair Area to determine the actual manpower costs from April 1, 1971 through August 21, 1971. Based on the savings accrued during this period, it was estimated that the actual savings for this area at year end would be approximately $171,000. This was about $10,000 better than the savings estimated for the modified third shift with the skeleton crew implemented in April.

Cycle time figures were approximately four percent higher than those simulated in March 1971. Engine production was down from March 1971 predictions by about twenty percent; however, the engine inputs were also below forecast by the same amount.

MANAGEMENT ANALYSIS AND PARTICIPATION

The success of using this simulation technique could primarily be attributed to the operating managers involvement through participation in formulating the models to simulate. This represented a real world consideration because these managers had been responsible for forming and analyzing manpower allocation prior to simulation. And, in many ways, their insight into this model made them more knowledgable in making the analysis.

REFERENCE: 1. International Business Machines Corporation, "General Purpose Simulation System/360 - Users Manual (H20-0326-0)"