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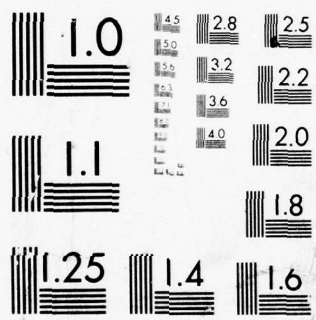
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(6) MANPOWER PLANNING THROUGH

MATERIAL REQUIREMENTS PLANNING (MRP):

A COMPUTER SIMULATION.

BY

(10) DAVID A. WILKERSON

(9) Doctoral thesis,

A Dissertation Submitted in Partial Fulfillment of the Requirements for the Degree of Doctor of Business Administration in the Graduate School of Business of Indiana University

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ABSTRACT

Effective manpower planning becomes quite complex and critical in high technology environments. In these environments, operators and maintenance personnel must be highly trained and skilled to assure that equipment will be effectively utilized, and so that changes can be rapidly implemented. The manpower planning problem becomes one of determining requirements for skilled employees early enough to ascertain training needs, to select candidates for training, to educate and train technicians before a shortage of manpower occurs, and to achieve this without excessive manpower costs.

This investigation examined definitions of the manpower planning problem; briefly surveyed traditional approaches to manpower planning; and presented an alternative technique, material requirements planning (MRP), which has been successfully applied in other kinds of planning problems. The general hypothesis tested was that MRP will be a more effective procedure than traditional extrapolation techniques for manpower planning. The test of the hypothesis involved comparison of a manpower planning model using MRP concepts with one using traditional extrapolation concepts through a model of a simulated Air Force weapon system. All of the system specific information included in this investigation has been approved by United States Air Force Institute of Technology Office of Information (USAFIT/OI) and is considered non-sensitive information.

The results showed that in relatively stable environments both types of models maintained the prime objective, keeping missiles on alert, but the MRP approach achieved the alert rate at a lower total cost (i.e., with

fewer maintenance teams). Additionally, MRP proved superior to the extrapolation model in very turbulent or uncertain environmental situations. The turbulence was created by changing the configuration of the missile system.

This investigation provides a basic foundation for testing the MRP concept under various environmental conditions and has demonstrated that simulation is a very useful method for research, and provides a new approach and expanded definition of manpower planning.

MANPOWER PLANNING THROUGH MATERIAL REQUIREMENTS PLANNING (MRP): A COMPUTER SIMULATION

BY

DAVID A. WILKERSON

A Dissertation Submitted in Partial Fulfillment of the Requirements for the Degree of Doctor of Business Administration in the Graduate School of Business of Indiana University

Chairman: Professor Thomas E. Vollmann

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1976

ACCEPTANCE

This dissertation has been accepted in partial fulfillment of the requirements for the Degree of Doctor of Business Administration in the Graduate School of Business of Indiana University.

Date June 21, 1976

Dean, School of Business

Chairman

William C. Perkins
Member

John C. [illegible]
Member

Henry P. [illegible]
Member

DEDICATION

To my wife, Janet,

whose support is lovingly appreciated;

and all women who want to be women.

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ABSTRACT

Effective manpower planning becomes quite complex and critical in high technology environments. In these environments, operators and maintenance personnel must be highly trained and skilled to assure that equipment will be effectively utilized, and so that changes can be rapidly implemented. The manpower planning problem becomes one of determining requirements for skilled employees early enough to ascertain training needs, to select candidates for training, to educate and train technicians before a shortage of manpower occurs, and to achieve this without excessive manpower costs.

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CHAPTER I

INTRODUCTION

Manpower planning is the task of "anticipating human resource requirements, taking into account current and likely future demands for skills and probable availability of individuals with such skills."[1] Since successful manpower planning demands a balance between skill required and skill available at some future time, then the planning necessarily must be complete prior to the minimum lead time for acquiring and training new personnel. In environments where personnel procurement lead times are short and/or future needs can be readily extrapolated from historical trends, manpower planning is relatively simple and straightforward. However, for a high technology case,[2] such as maintenance requirements for complex defense systems, training times can be long and equipment design changes can significantly change the mix of skills required. This study will adapt a proven planning technique (material requirements planning--MRP) from a production and inventory control context and apply that framework to manpower planning.

The need for accurate, long-range manpower plans is more important today than at any time in the past due to our dynamic society and ever increasing level of technology. Most of the current manpower planning

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[1]The Encyclopedia of Management edited by Carl Heyel, 2nd Ed., (New York: Van Nostrand Reinhold Company, 1973), p. 523.

[2]A high technology environment is an environment in which the product or process of making the product is very complex (requiring many individual components) and the configuration of the system or product changes rapidly, the information processing is complex and requires large quantities of minor bits of information and monitors or controls the process by artificial intelligence, and technicians must be highly skilled and require long periods of time to acquire the necessary skills either by training and/or experience. This definition was developed by the author based in part on Emery and Trist (1965), Hall and Hager (1969), Lawrence and Lorsch (1969), and Terreberry (1968).

approaches tend to break down in a high technology environment when the configuration of the product (or the process of making the product) changes rapidly, creating a situation in which highly skilled technicians must be acquired, trained, or retrained in order to operate or maintain the newly configured system. The resultant effect of this rapid change process on manpower requirements is often very complex and difficult to analyze through traditional manpower planning techniques.

A recent survey by the Industrial Relations Center at the University of Minnesota indicated that ten out of eleven firms surveyed had some type of formal manpower planning programs; however, they were not much more accurate than chance.[3]

Theoretical Framework

Manpower Planning

Definitions. Manpower planning has been defined in many different ways depending on the inclination of the author. Some have been very broad, such as Coleman (1966, pp. 4-5) when he defined it as " . . . the process of determining manpower requirements for carrying out the integrated plans of an organization. It encompasses types of skills and capabilities, number of people, and location and timing of manpower needs."

Some have provided very specific definitions, such as Vetter (1967, p. 15), who said manpower planning is ". . . the process by which management determines how the organization should move from its current manpower position to its desired position. Through planning, management strives to have the right number and right kinds of people, at the right places, at the right time. . ." and Krajewski and Thompson (1975, p. 315), who define

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[3]"Manpower Planning: A Research Bibliography," (Industrial Relations Center, University of Minnesota, January 1970).

it as the ". . . determination of a work force level for each period of the planning horizon such that employment-related costs are minimized and service is maintained at an acceptable level."

Burack (1972, pp. 58 & 72) goes much farther and distinguishes between manpower planning and manpower programming. Starting with the definition of manpower planning given by Porter which says manpower planning is "Striving to have the right number and right kinds of people at the right places, at the right times, doing things which result in both the organization and the individual receiving maximum long-run benefits," Burack breaks it into two components, planning and programming. Manpower programming includes those activities which are directed toward the individual such as recruitment and placement, appraisal, analysis and performance review, education and development, and motivation and compensation. Manpower planning, on the other hand, must deal with forecasting the right number and right skill of individuals required at some point in the future. It must therefore be a future-oriented process, and it must be built around the goals or objectives established by the organization. This then will be the definition of manpower planning used in this dissertation. It is very similar to the definition previously established by Vetter (1967).

Purpose of Manpower Planning. Many reasons and requirements for manpower planning have been established and reiterated, but regardless of the specific tasks, the necessity for adequate planning involves two basic factors: cost and availability. Increasing cost of manpower is forcing planners to search for more accurate methods. In a recent Air Force Commander's Newsletter[4] it was mentioned that more than one-half of the 76 billion dollar Defense Budget was dedicated to manpower costs. As

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[4]Supplement to Air Force Policy Letter for Commanders (Washington, D.C.: Office of the Secretary of the Air Force, Internal Information Division, AFRP 190-2, Number 1-1972, January 1972), p. 15.

equipment and systems become more sophisticated, workers must have higher skills, forcing manpower costs to rise dramatically. It becomes essential to have the proper inventory of manpower skills, with minimal excesses and shortages. Moreover, these skills may become more difficult to obtain due to necessary training or experience so the second factor, availability, now becomes equally important. Overages of personnel are very costly, but shortages of the right skills can even be more costly if the flow of work must be slowed or stopped entirely. The larger and more complex the organization becomes, the greater the possibility of bottlenecks caused by inadequate determination of skill, place, or time for manpower needs. The complexity of planning for manpower requirements and the necessity for accurate time-phased plans have led to recent interest in the derivation of manpower requirements and models for analysis of those requirements. Greenlaw (1973) summarized many manpower planning methods. Others who have worked in this area include Bain (1968), Baum, Bernard, and Burack (1973), Burack (1972), Coleman (1966), Hasse (1966), Martel and Al-Nuami (1973), Morton (1968), Rowland and Sovereign (1969), Tetz (1973), Vetter (1967), Walker (1970), Wikstrom (1971), Wilson (1969), and Wortman (1970).

Traditional Manpower Planning (TMP) Methods. There are many methods for forecasting personnel requirements ranging from causal observation and "rule of thumb" methods to very complex mathematically derived models. Morton (1968) identifies five general model categories for manpower planning:

1. Curve-fitting techniques
2. Drived manpower forecasts
3. Direct manpower forecasts
4. Econometric models
5. Operations research methods

All of these general model categories are based upon extrapolation of historical data. Morton indicates that category 3, direct manpower forecasts, is the most widely used. The types of forecasting models used include moving average and exponential smoothing, with trend and seasonal influences incorporated as necessary. In keeping with this approach, the basic method used as representative of traditional manpower planning (TMP) was regression.

Material Requirements Planning (MRP)

What is MRP? MRP is an approach to scheduling production and providing the exact materials necessary to support the production schedule. Before MRP can be fully explained, the concept of dependent demand must be established. A good example to illustrate the benefits of dependent demand over typical independent demand inventory approaches is to examine the household pantry. The independent demand approach would derive a shopping list (analogous to orders) from a review of pantry stocks (analogous to inventory levels in an order point system), with order quantities being based on historical use and price discounts. The dependent demand alternative is to plan menus for the next several days (master schedules), determine necessary ingredients and their quantities from recipes (bill of materials), pass the projection of required ingredients against existing pantry stocks (gross to net), and subsequently derive the shopping list.

There is little doubt that the dependent demand approach will produce fewer shortages (stockouts) and a lower average inventory. The demand for ingredients is not based on a straight line extrapolation of past usages as if there were no control over the use. The demand for ingredients directly derives from the master schedule or planned future menus, and the demand quantities can be calculated exactly from recipes and pantry inventory data.

The unthinking nature of order point systems is also well illustrated by the pantry example. Under order point or some other independent demand review system, a replacement order would be triggered when a commodity was used. Thus, poultry seasoning might be purchased right after Christmas, even though no demand is likely until the following Thanksgiving. The same concept is followed by manufacturers: orders are released for component parts immediately after their being "consumed" in assembly, but another assembly (use) may not be required for some time.

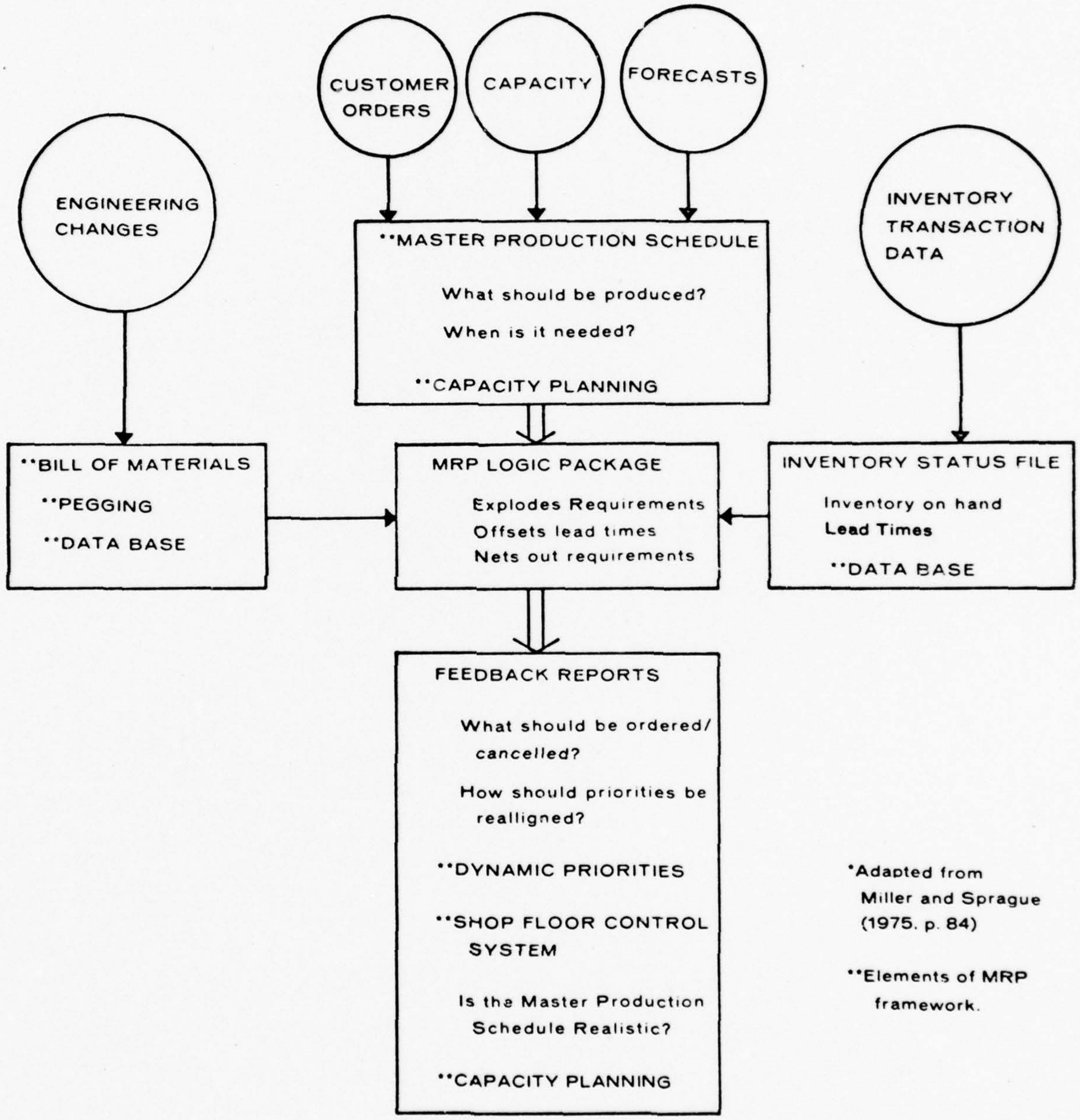
The concept of dependent demand versus independent demand was first formulated by Orlicky in 1965. By 1968 material requirements planning was beginning to emerge as a viable theory of production and inventory control. IBM produced the first application program using this integrated approach. This program, called Production Information and Control System (PICS), proved to be successful. More recently, IBM has developed the Communications Oriented Production Information and Control System (COPICS). A related development has come from those companies which were installing MRP type systems; active communication channels have been established, primarily through the American Production and Inventory Control Society (APICS). Several individuals such as Orlicky, Plossl, and Wight have emerged as key spokesmen for the approach. The potential is clearly recognized by the 11,000 members of APICS who are spreading the "gospel" through technical channels. "By the mid-1970's, many observers commented that 'everyone is singing from the same hymn book.' The leading consultants, the literature, movies, video courses, and education programs sponsored by the American Production and Inventory Control Society (APICS) were all saying the same things about the same techniques." Wight (1974, p. viii)

In a variety of practical applications MRP has been shown to be superior to other methods for production and inventory control. Of course, MRP has not been successful in every application, but the basic concepts of MRP appear to be a better way of looking at production and inventory control. MRP is considerably more than a means for launching replenishment orders; MRP also reschedules existing orders, cancels orders not needed, and provides continually updated priority data for shop priorities. "The logic of MRP is based on the fact that the demand for materials, parts, and components depends on the demand for an end product." [Miller and Sprague (1975, p. 85)] Once the need for the end product is established, then the demand for all other parts and components becomes deterministic. So with MRP, production goals are set and all activities are directed at doing the right job at the right time to meet those goals. The difference between traditional production and inventory control methods and MRP is analogous to the difference between activities-oriented management and results-oriented management as specified by Mee (1972, p. 33). Results-oriented management, like MRP, allows managers to "proact" to future desired results rather than "react" to environmental factors as traditional production and inventory control methods and activities-oriented methods must. The basic concept, then, of MRP is not new; but due to increased data processing capabilities and practice, MRP can now be applied to systems which are enormously complex because of data base size.

How MRP Works. The five major components of an MRP system are shown in Figure 1: the master production schedule, bill of materials, inventory status file, MRP logic, and feedback reports.

The "master production schedule 'drives' the system, the bill of materials file, the inventory status file that provides the necessary data, and the material requirements planning package that contains the necessary logic." [Miller and Sprague] This master schedule shows what end items should be produced and when they are needed. It establishes

COMPONETS OF A MATERIAL REQUIREMENTS PLANNING (MRP) SYSTEM*



*Adapted from Miller and Sprague (1975, p. 84)

**Elements of MRP framework.

Figure 1

rough capacity planning through a two-step process. First, the necessary capacity can be established; second, the amount of capacity available under various circumstances can be considered. The necessary capacity can be based on "released orders" (those to which the company is committed) and "planned orders" (those which are forecasted commitments) under no constraints. These capacity needs are usually expressed in time buckets or weekly units, and peak-valley variations from week to week are smoothed out where possible. Next the smoothed weekly requirements are compared to available capacities. If a suitable match between capacity and needs is achieved, then production rates can be established; and the capacity planning task shifts to the work center level.

If sufficient capacity is not available for any or all of the requirements, expectations must be revised; either the capacity must be increased or the master schedule must be reduced. In an MRP system, the production plan includes only what can realistically be produced, regardless of commitments. Capacity can be increased through overtime, subcontracts, alternate production methods, and other means. The MRP system merely tells the planner what needs to be done but not how to do it. It is his or her decision whether to supply the customer through alternate routes or to reduce the master schedule and make customers wait until later time periods.

The data base must contain sufficient information and capability to fully manipulate master production schedule variables in the manner desired. The data base will have two major components: the inventory status file and the bill of materials. There will also be many subfiles for accounting, budgeting, and record control operations. The inventory status file keeps track of the amount of inventory on hand, lead times by product, and open orders along with inventory item description data.

The bill of materials is a "listing of all the sub-assemblies, parts, and materials that go into an assembled product showing the quantity of each required to make one assembly." (APICS Dictionary, p. 4) There are many ways to structure the file, but the important point is that the structure chosen should reflect the needs of the organization.

Requirements tend to change over time due to changes in technology, customer desires, inventory adjustments, and many other reasons. Pegging is the MRP term used for keeping track of the source of the end item which generated a particular component part need. This allows the planner to identify every requirement associated with a change and thereby facilitates expediting/de-expediting, when necessary, and provides more control over what should be ordered and when.

Obviously, all orders cannot be perfectly planned nor all contingencies fully anticipated. A system called shop floor control system attempts to compensate for these irregularities. The shop floor control system adjusts task priorities in light of partial work completions and updated priority requirements. Controlling the processing of materials through various stages has always been a difficult task. The critical difference in the MRP oriented system is that the information on final needs is always less imperfect. The shop floor control system in an MRP environment boils down to effective priority control and queue management and depends on accurate and reliable priority control information. This information provides the line manager (foreman) with effective guidelines for how to schedule his department each day. The foreman's objective is to take this information and move orders through his department on time as well as utilize machine center capacity.

Manpower Planning and MRP

Objective. All approaches to production and inventory control have as a goal the provision of sufficient inventory to meet production needs. The MRP based system tends to achieve this goal with lower inventory levels, fewer stockouts, and increased productivity. The MRP approach is to always be working on the right job at the right time. To do this, component parts must also be available in inventory as with traditional concepts, but now the point of focus is on the right job. MRP is future oriented compared to the past or historical orientation of traditional systems. The manpower planning objectives similarly are to have a sufficient number of people available to work, and to have the right individual working on the right job at the right time. With this objective, the problem shifts to determining the right job. It is the objective of this research to determine if MRP is a better method for determining the right job for manpower requirements, and under what conditions this might or might not be true.

MRP for Manpower Planning. The concept of dependent demand, bill of materials, and other MRP system components can be applied to high technology manpower planning. In the same way that demand for component parts can be deterministically estimated by the explosion of master schedules through the bill of materials into time-phased records, future manpower needs for highly complex systems can be predicted by exploding the final system configuration into successive subsystems with known mean time between failure data and ages of components. The concept of dependent demand applied to manpower planning means that the amount and timing of manpower requirements are based upon the configuration of the system that is being manned or reviewed. Whenever there is any change foreseen in that structure, the resultant manpower needs are projected from the new planned system configuration. Thus, for example, if a particular device were built from components with certain mean expected times between failure, appropriate preventive maintenance policies could be developed; these policies represent relatively predictable, dependent needs for maintenance personnel. A learning curve should be anticipated and plans should include this. If a design modification changes the mean time between failures, a new preventive maintenance policy must be developed, precipitating changes in required manpower. Similarly, if actual experience calls for revisions in estimated mean time between failures, new personnel requirements may result. The traditional (independent demand) approach would extrapolate manpower needs from historical use of the manpower. Historical data would be manipulated with no look forward.

The Specific Application

Background of the Problem

The Minuteman Intercontinental Ballistic Missile (ICBM) system will serve as an example for the application of a dependent manpower planning system in a high technology environment. The Minuteman system is very sophisticated with a remove-and-replace concept. Maintenance teams must respond to component failures, "fault analyze" to locate faulty components and replace faulty equipment when necessary. One of the most complex problems of the maintenance manager is to determine maintenance team requirements. He must determine how many of the various types of maintenance teams must be qualified and available for work. He must then consider the available supply of skills and compose the number of required teams and insure that they are properly trained. This process must be accomplished monthly and projected approximately one year in advance.

The requirement for qualified Minuteman maintenance teams is determined by a very involved arithmetic method based on trial-and-error.

Historical information is maintained on the utilization of each type of maintenance team which is analyzed and future requirements are then projected. When conditions change or systems are modified, the trial-and-error process continues as effects of changes become obvious. First, because of the inability of the approach to consider the many complex interrelated and aggregated variables, but even more significantly due to its lack of future orientation, this process often leads to over supply or under supply of certain skills. The approach is basically an extrapolation method since it uses historical data and then projects known data to determine future requirements.

The actual Minuteman system requires more than having the right skills on hand at the right time. It requires bringing personnel and various equipment together for specific tasks. The following figure shows the general relationship between personnel and equipment variables.

PERSONNEL and EQUIPMENT REQUIREMENTS for MAINTENANCE TASKS

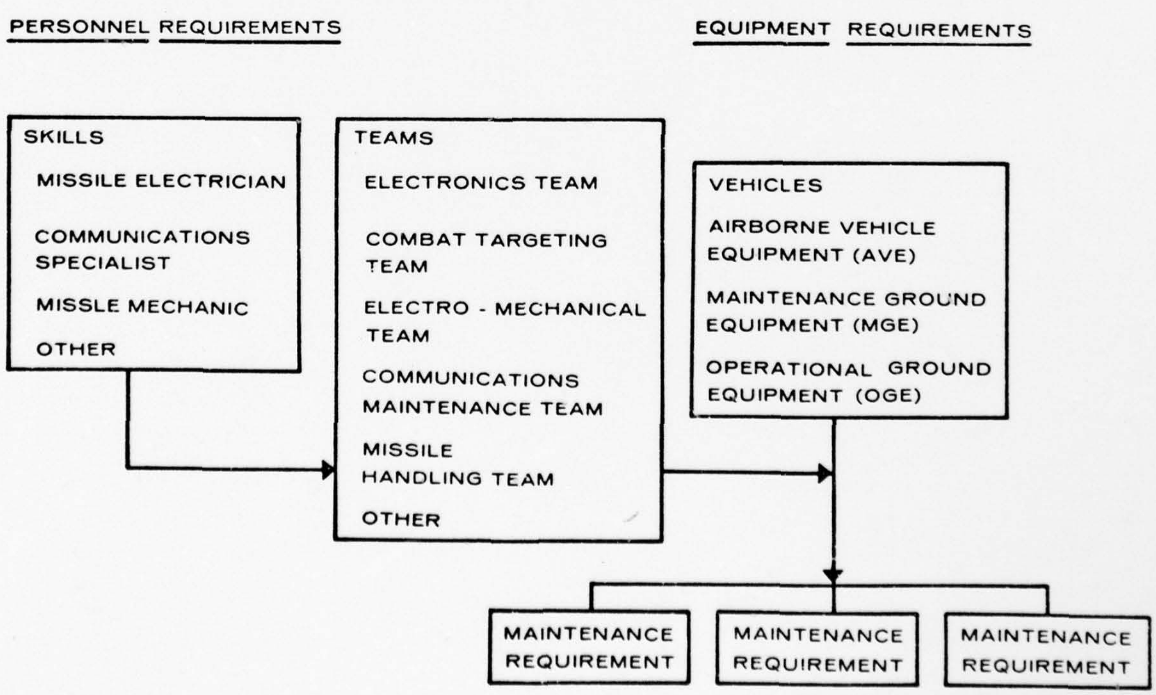


Figure 2

Teams must be trained as integral units beyond the training required for individuals in each team. In other words, a Missile Electrician on a Combat Targeting Team cannot move automatically to an Electro-Mechanical Team without additional training. Those teams plus the equipment required must be brought together in the right combination to perform various maintenance functions. The need is to identify the total number of each skill required in sufficient time to insure that trained teams are available when required. All of these situations of the job can be considered as part of the bill of materials. A computer simulation model will be used to simulate this type of information and will change the structure of the bill of materials as a means of evaluating the various systems.

Why MRP?

The structure of MRP is applicable for manpower planning for two main reasons. First, MRP has a forward orientation which starts with the end requirement and explodes backwards to determine basic component needs. Second, the operating MRP support subsystems include the capability to more effectively respond to major and minor changes. In operation, MRP has the capability of adapting to a changing environment, repeatedly taking advantage of the latest available information. The Minuteman ICBM and other high technology systems are being constantly improved and modified; MRP provides the promise of a more effective means to keep pace with steady evolution in system configuration.

Even more important than steady evolution in system components and maintenance policies are major modifications of the system or changes in system objectives. For example, a missile system could incorporate a whole new targeting concept, incorporate multiple warhead technology, or incorporate a change in its strategic objectives. The resultant derived changes in manpower needs can be quite significant.

MRP is a "real time" system. As such, it has the capability to constantly replan, incorporating actual data, and then plan again based on most recent actualities. Since most of the forecasts upon which the sequencing and duration of tasks are based depend on underlying frequency distributions, this capability of including the most recent actual data is quite attractive and provides a direct link between the system dynamics and the planning network.

Another attractive feature of MRP is its adaptability to similarly configured systems. For example, if a totally new weapon system were designed for our missile forces, it would be similar in many respects to existing missile systems. Estimates could be determined for mean time before failure for each of the new components based on existing systems and the manpower requirements could be estimated from the latest information acquired during the development and testing stages of the system. As more about the new system becomes known, estimates can be improved and the entire planning process will adapt.

CHAPTER II

THE SIMULATION MODEL

Experimental Environment

Comparison Technique. The two basic experimental conditions or methods for manpower planning to be tested--MRP (material requirements planning) and TMP (extrapolation or tradition manpower planning)--will be applied to the maintenance of a simulated intercontinental ballistic missile squadron. By experimentally modifying the nature of the maintenance activities, comparisons can be made for equipment maintenance ranging from the relatively mundane to sophisticated changes inherent in a "high technology" environment (see Appendix A for a detailed flow chart of the model). The model will be designed to simulate the operation, failure, maintenance repairs, and modifications of 30 missiles with 10 components each. The number of missiles and components can easily be varied. Appendix D shows a list of the variables associated with the missile components: mean time before failure (MTBF), maintenance priority, team required to repair each component, and mean repair time. Priority rules are also included in Appendix D. These variables become parameters of the simulation model along with such exogenous variables as travel time between missile facilities and preventive maintenance decision rules. The two manpower methods will operate for the same length of time and comparisons will be made based on criterion variables.

The simulation language will be GASP II which is FORTRAN based. GASP II is an event oriented simulation language which sequences event types created by the programmer. GASP appears to be the best method since it can make use of FORTRAN subroutines for MRP, TMP, and others, and it will automatically keep track of statistics and sequencing.

Criterion Variables. Several criterion or dependent variables will be observed to measure differences due to experimental conditions.

Manpower Cost Variables (three teams)
- Idle time for each team
- Idle time variance for each team
- Total idle time
- Variance in total idle time

System Performance Variables (30 missiles/10 components each)
- Strategic alert rate
- Strategic alert rate variance
- Stockouts (number of components down and waiting)
- Stockout variance

The above variables will be measured for each time period (week). Idle time, by team, will be calculated each time an event occurs so that by the end of the run the mean weekly idle time for each team will have been collected. Weekly idle time can then be totaled to obtain the total idle time for all teams.

Likewise, strategic alert rate and missile down and waiting time will be collected each time an event occurs and mean values will be calculated weekly. Variance for all variables will be collected and updated throughout the run.

Alternative Manpower Planning Model Definitions. Two experimental conditions or independent variables will be used in this investigation: MRP and TMP.

In the MRP experimental condition, the master schedule will be built based on the mean time before failure and known system configuration requirements. This will then be exploded through the data base (maintenance team structures and team assignments) and time-phased requirements will then be compared to manpower inventory levels (gross-to-net). Differences between manpower requirements and available personnel will be analyzed and orders for specific skills will be issued, cancelled, or held based on the expected lead time for each action.

The TMP experimental condition is based on an extrapolation of historical data. A manpower forecast will be made based on a trend analysis consisting of cycle, trend, and error variables. Shortages and overages will be handled similar to MRP.

Structure of the Model

The basic structure of the simulation model can be seen in Appendix A (Flow Chart) and specific detail can be obtained in the program listing in Appendix B. The simulation model has an initialization routine and six subroutines. In the initialization routine of Program MANPWR all variables which require starting values are initialized. For example, initial values are assigned to the number of missiles and components; the travel time to and opening time for missile sites; the number of and lead time to acquire each type of maintenance team; the statistical variables; the requirements matrix (for storing expected manpower needs by team) and the order matrix (for storing the number of each type of team ordered for each week up to the planning horizon); and the length of each planning point (one week or bucket equals 168 hours). Finally, the initialization routine must establish the parameters for the teams and missile components. The priority of each component and the team required to repair each component are specified. The mean-time-between-failures and repair time for each component are specified.

The first subroutine is SUBROUTINE EVENTS. Here the event selected by the GASP Executive subroutine (the next event in the future events file) is used to select the appropriate subroutine to execute the activities required by the selected event. That event may be a missile failure (SUBROUTINE FAIL), a missile which has been repaired (SUBROUTINE FIXED), an indicator that a week has ended and the next forecast must be made (SUBROUTINE FORCST), an indicator that the new missile must be loaded into the future events file or removed from the system (SUBROUTINE LOAD), or an indicator that the simulation run is completed (SUBROUTINE ENDSIM).

SUBROUTINE FAIL begins by collecting statistics of occurrences up to this point and then checks to see if the right type of maintenance team is available. If the right type of team is available, then statistics are again collected to determine idle time of maintenance teams and the number of maintenance teams in use and a counter is tripped to indicate that one more maintenance team of the type being considered is in use. Since a component of one missile has failed and is being repaired, that missile is taken off alert and statistics are collected on missile status. A repair time is generated from the Poisson distribution using the mean repair time for this component established in the initialization routine. An event indicating the end of repair on this component is placed in the future events file while the component is being repaired.

If the right type of maintenance team is not available, then the program determines if this new failure has priority over any other failures now being repaired. If the new failure is priority two or three, then it is placed in the queue or waiting line for this type of team, in order of priority and failure time. The lowest priority is the first to be repaired and within priorities, the earliest to fail is the first to be repaired (i.e., a FIFO or first-in-first-out system). If the new failure is priority one, then the program searches the future events file for components being repaired by this team and looks for any priority lower than priority one: It will select the lowest priority first. If only priority one components are being repaired, then this new component will go in the queue for this team, again by priority. If a lower priority component is found, then work on that component is stopped immediately and a missile site close-up time of .5 hours is added to the repair time for the new component. The old lower priority component is then placed in the queue for this team since the team is now put to work on the new higher priority job. Any time a component of priority two or three has failed but is not being repaired, the missile will remain on alert; and any time a missile is being repaired, it will be off alert.

SUBROUTINE FIXED begins by collecting statistics on the number of components currently being repaired and the time each component now fixed remained in the system. Other statistics are updated and then this component is placed back on alert. A new failure time is generated from the Poisson distribution based on the MTBF (mean-time-before-failure) of the component. Now the program checks to determine if there are components waiting for this team. If there are no components waiting for this team, then the team is placed in idle status, appropriate statistics are collected, and a counter reduces the number of busy teams of this type by one.

If there is a waiting line for this type of maintenance team, then the program selects the component with the highest priority which has been in the queue the longest. First the program must determine if the missile waiting is on alert or off alert (priority one). If this missile is not off alert, then it must now be taken off alert while being repaired and alert status statistics must be updated. Finally, a repair time is generated from the Poisson distribution based on the mean repair rate for this component.

The basic simulation model is contained in the two subroutines above.

The program will operate with a constant number of maintenance teams and maintain all statistics based on these two subroutines.

SUBROUTINE FORCST is required to tabulate weekly statistics and to make forecasts for as long as necessary into the future. Most of this subroutine is common to both Material Requirements Planning (MRP) and Traditional Manpower Planning (TMP).

This forecast subroutine begins by calculating the average number of each type of team used during the previous week. It sets up counters for the experiment and run numbers, for alternative sampling, and then calculates the average idle time per team, average waiting time (time that components waited for the right team), and the alert rate for the previous week.

Statistics are all printed the ninth week and every week thereafter but data used for analysis are not put on tape or punched on cards until the 50th week. This is part of the start-up procedure and is necessary to insure that trends caused by the initial conditions are not present.

Next, orders are all moved forward one week in preparation for the coming forecast and following week. Basically this causes the number of teams assigned to be changed by the incoming order (this may be negative or positive depending on previous forecasts) and the forecast period to stretch one more week into the future as the current week is assimilated into the model. The forecast comes next and covers about one fifth of the forecast subroutine. First, the MRP forecast logic and gross-to-net method will be discussed. Then the differences based on TMP will be presented.

SUBROUTINE ENDSIM is required to terminate the simulation. All time dependent statistics are collected for the final time and control is given back to the GASP II Executive subroutine to calculate and print statistics for the total simulation run.

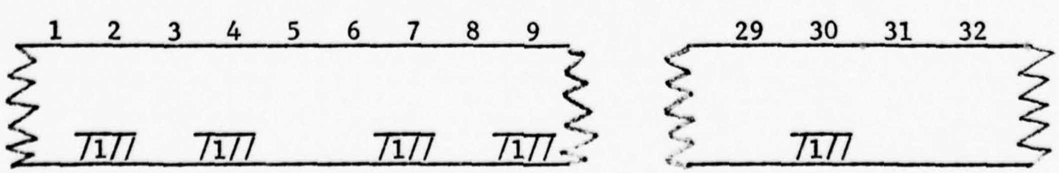
DATA CARDS are brief but provide control for the entire GASP II program. Basically, the data cards establish the number and type of statistics to be collected (statistics were also collected independent of GASP II for this investigation), the size of the NSET array which stores future events, the number of queues, the way in which each file is to be arranged, and initial events for SUBROUTINEs LOAD, FORCST, and ENDSIM.

Material Requirements Planning (MRP) Method

The heart of the MRP method is the master schedule. The master schedule is designed one task at a time until all expected tasks up to the lead time for obtaining new teams are considered.

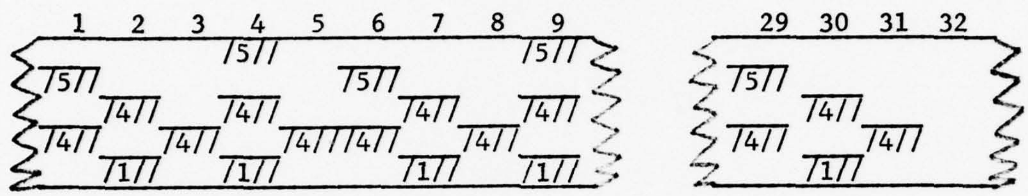
First, component one of missile one is examined. The program starts with the last time the component failed and then adds the average failure rate of that component to determine the next time that the component is expected to fail. The team-hours required to repair this component are added to the time bucket (week) in which this failure is expected to occur. The program then adds the average failure rate again and places the team-hours required for repair in that weekly time bucket. This process continues until at least one week beyond the frozen period or lead time required to obtain new teams.

TEAM 1 (Missile 1; Component 1)



The cross-hatched area in the above figure indicates the time buckets in which component one of missile one is expected to fail and repair by team one will be necessary. This process will continue for missile one until all ten components have been examined and the times for expected failure have been calculated. Since team one is designated to repair components one, four, and five, the following chart shows a possible master schedule for team one if only one missile were considered:

TEAM 1 (Missile 1; Components 1, 4, 5)



The team-hours for each expected task (each component of each missile over time) are added to the respective time buckets as the program continues until all missiles are considered. These totals show the manpower needs by week. *Once requirements are known then* a gross-to-net calculation takes place to determine the final need.

Traditional Manpower Planning (TMP) Method

This method differs from MRP only in the method of determining manpower requirements. First, maintenance team utilization data are collected based on the average number of each type of team used for each week. To this average, a safety stock (percentage of the average), was added before the final figure was used in a regression model to forecast manpower requirements by team type.

Common Ground Rules

Certain ground rules were established, not because they were the best, but because they were sufficient. An unlimited variety of rules could be developed and tested to find the best rules for the situation but as the situation changes so do the rules. The common ground rules listed below were those used for this investigation.

1. Forecast horizon - The forecast period is designed to be one period beyond the lead time required to obtain new maintenance teams.

2. Frozen period - The frozen period for each team is the lead time required to obtain new maintenance teams. Maintenance teams cannot be ordered in less than the lead time. The frozen period varies by team as follows:

TEAM	FROZEN PERIOD
1	30 weeks
2	20 weeks
3	10 weeks

3. Rule to add new teams - The order for lead time plus one period is the projected manpower need minus the number of teams of the type being considered expected to be available at that time. Fractions of teams required were rounded up to integer form.

4. Fire rule or rule to subtract teams - Teams can be subtracted with a lead time of eight weeks. The rule is this: If gross-to-net calculations show an overage of the average number of teams required in periods eight, nine, and ten (8, 9, and 10), then that overage was subtracted from the order for period 8.

5. Rules for collecting data

   a. Idle time - Idle time was calculated each time the number of teams available or in use changes. It is a measure of the percentage of teams available to those in use.

   b. Strategic alert rate - The number of missiles available for use was calculated every time that number changed. Only failure of components having priority one or two could take the missile off alert.

c. Stockouts - The number of components down and waiting for a maintenance team was calculated automatically by the GASP II program.

d. The number of teams assigned was calculated the same way as idle time.

Summary

In summary, the simulation model was basically a GASP II program with event routines to handle missile component failures, repaired components, weekly forecasts, loading of failure times, and an end of simulation. Three types of maintenance teams with 10 to 30 weeks lead time to acquire new teams, were assigned to repair 10 components per missile for 30 missiles. Common ground rules were used so that the only difference between the two methods of manpower planning was in the method of determining manpower requirements. The next chapter explains the situations under which these two methods were compared.

CHAPTER III

EXPERIMENTAL DESIGN

Introduction

This chapter explains the design of four experiments to compare the material requirements planning (MRP) concept of manpower planning to an extrapolation method of manpower planning called traditional manpower planning (TMP). The experiments range in complexity from the stable state of Experiment 1, through the turbulent environmental conditions of Experiments 2 and 3, to the uncertain environmental condition of Experiment 4. The variables, environmental situations, and the configuration modifications which cause those situations are explained. Finally, the purpose and levels of each experiment are established. The chapter concludes with a summary and an experimental summary chart.

Variables

The following figure conceptualizes the flow of the experiment.

EXPERIMENTAL FLOW

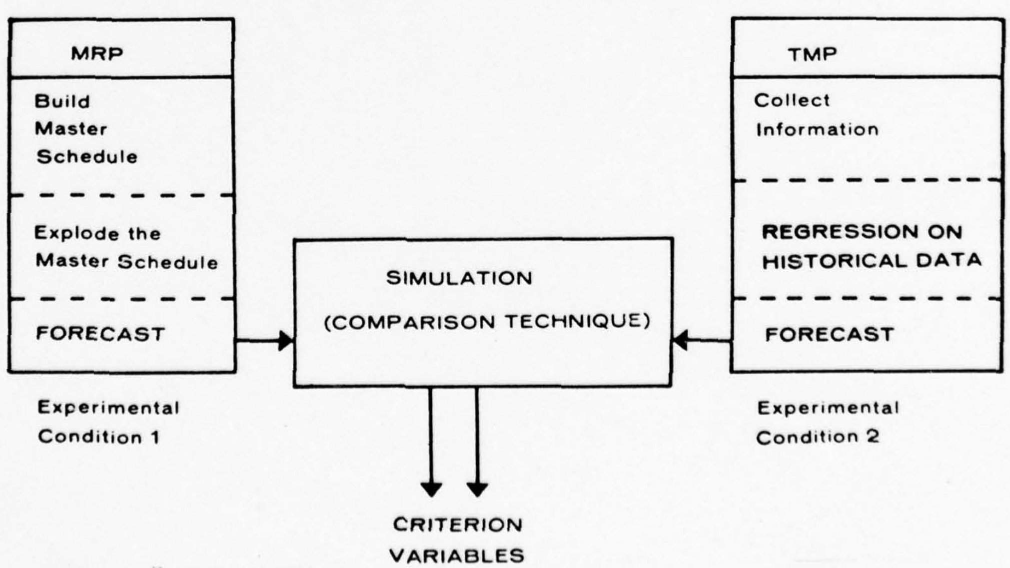


Figure 3

The major hypothesis tested was that a manpower planning model based on material requirements planning (MRP) concepts will be superior to models based upon extrapolation of past conditions. Surrogate measures for this hypothesis include:

Manpower Costs
System Performance

Environmental Situations

The two manpower planning models were evaluated under four basic maintenance conditions or levels of maintenance requirements:

1. Steady state - The simplest environmental situation
   a. No change in the configuration of the system.
   b. Constant number of missiles and components.
2. Modifications to the configuration of the missile system occur and each type of configuration modification is tested separately.
3. Modifications occur simultaneously.
4. Emergency modification occurs:
   a. Must be implemented as soon as possible with only one week advance notice.
   b. Requires the highest priority.

Configuration Modifications

The following four types of modifications were used in the investigation:

1. MOD 1 - This modification required a change in the mean time before failure (MTBF) of a missile component.
2. MOD 2 - This modification required a change in the time required to repair a missile component.
3. MOD 3 - This modification required a change in the team assigned to repair a missile component.

4. Simultaneous modification - Each simultaneous modification was a combination of 1, 2, and 3 above.

Analogues can easily be found for the experimental situations and configuration modifications listed above. Modifications of all sorts are found in the actual missile system. The decision to limit each modification to one variable should allow a more complete analysis of the missile system. MODs 1, 2, and 3 will be applied in separate runs to rule out order effect and to better see the effects of each modification.

Experiments

Each of the four experiments compared MRP versus TMP under the various environmental conditions. Also the results of each experiment were compared to the steady state results of Experiment 1 for the respective experimental condition (i.e., MRP or TMP). The purpose and levels of each experiment are:

1. Experiment 1: Steady State
   a. Purpose - To establish some basic decision rules and to serve as a standard by which to compare the results of following experiments.
   b. Level - Constant number of missiles.
2. Experiment 2: Modifications without Overlap
   a. Purpose
      (1) To measure the difference in criterion variables between MRP and TMP with one modification per run.
      (2) To determine if there is a difference between the effect of MODs 1, 2, and 3.
      (3) To test existing manpower planning decision rules.

b. Levels

(1) MOD 1 - Change in MTBF

(2) MOD 2 - Change in repair time

(3) MOD 3 - Change in team assignment

3. Experiment 3: Simultaneous Modifications

a. Purpose

(1) To measure the difference between MRP and TMP with simultaneous modifications occurring.

(2) To test existing manpower planning decision rules.

b. Levels

(1) Simultaneous modifications occurring only once during the simulation run.

(2) Simultaneous modifications occurring two times during the simulation run.

4. Experiment 4: Emergency Modification

a. Purpose

(1) To test the capability of MRP and TMP to respond to emergency modification conditions.

(2) To test the effectiveness of decision rules under this condition.

b. Levels

(1) Simultaneous modification occurring once.

(2) Simultaneous modification occurring twice.

Summary

The experiments were designed to test the differences, if any, between the two manpower planning methods under various environmental conditions. Along with comparing the two methods within each experiment, the results of each experiment were compared with the results of Experiment 1 to determine if the experimental situations did, in fact, cause different effects as they became more complex. The next chapter explains the results of each experiment.

EXPERIMENTAL SUMMARY CHART

	PURPOSE	EXPERIMENTAL VARIABLES	CONDITIONAL VARIABLES AND LEVELS OF CONDITIONAL VARIABLE
EXPERIMENT 1	To investigate alternate manpower models under steady state conditions.	The major experimental variable is the manpower planning process: This is a qualitative variable assigned either MRP or TMP.	Number of Missiles Constant
EXPERIMENT 2	To investigate alternate manpower models under conditions of configuration modification with no overlap in modifications.	MRP vs TMP	Configuration Modifications - No Overlap 1. MOD 1 - Change in MTBF 2. MOD 2 - Change in repair time 3. MOD 3 - Change team assignment
EXPERIMENT 3	To investigate alternate manpower models under conditions of simultaneous configuration modifications.	MRP vs TMP	Simultaneous Configuration Modifications Occurring once Multiple occurrences
EXPERIMENT 4	To investigate alternate manpower models under conditions of emergency modifications to the configuration of the missile system.	MRP vs TMP	Emergency Modification Simultaneous modifications

Figure 4

CHAPTER IV

EXPLANATION OF THE RESULTS

Introduction

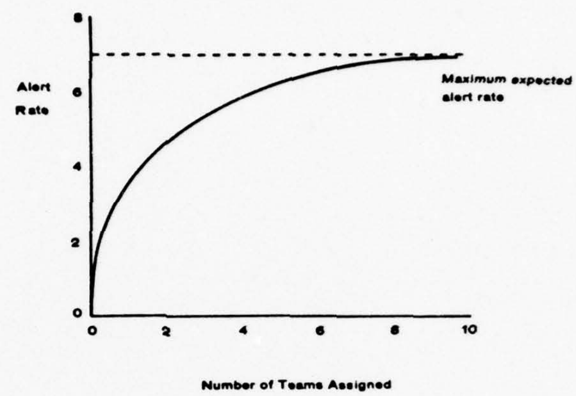
In this chapter the results of a sensitivity analysis on the variables and resulting adjustments to the basic simulation model will be examined. Then specific changes to the basic model in preparation for each experiment and the results of each experiment will be discussed followed by a brief summary. The entire chapter will then be summarized.

Sensitivity Analysis

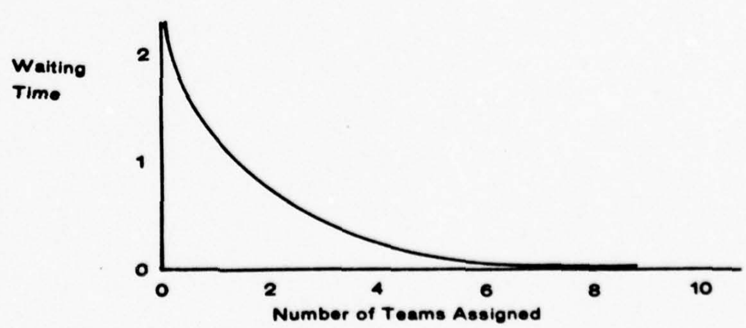
The purpose of the sensitivity analysis was to examine the effects of exogenous variables on endogenous variables. Exogenous variables are those which are determined outside the system while endogenous variables are those which are determined within the system as it operates. The results of the sensitivity analysis should indicate a range or level of each exogenous variable or starting value which would allow variation in the dependent variable. Very few variables affected the model beyond the start-up period. The sensitivity results are described in the sections that follow.

MTA (Number of Maintenance Teams Assigned)

The number of teams assigned was initialized at 11 teams of type 1, 13 teams of type 2, and 22 teams of type 3. These values were determined by allowing the model to operate for 10,000 hours with unlimited manpower assigned. From this starting point percentage increases and decreases were made to bracket those values for each team. It was found that the initial number of teams assigned has a curvilinear relationship with criterion variables. For example, MTA has the following relationship with alert rate:



It was found, and logically so, that there is a maximum expected alert rate. The alert rate will not increase beyond this maximum regardless of how many teams are assigned. Since waiting time (the time that components wait for the right team) tends to vary inversely with alert rate, a reflection of the above curve describes the relationship between the number of teams assigned (MTA) and waiting time:



Again, a limit is reached as waiting time goes to zero. On the other hand, idle time for maintenance teams as a percent of teams assigned continues to increase approaching 1.0 as the number of teams increases. The starting number of teams was 11 teams of type 1, 13 teams of type 2, and 22 teams of type 3.

MTBF (Mean Time Before Failure)

The mean-time-before-failure was varied and it was found that by increasing the MTBF for all components by a multiplicative factor of 10.0, the following occurred:

1. There was a significant reduction in the number of teams required (often dropping to zero).
2. The average number of missiles on alert increased from approximately 8 to 23 out of 30 missiles on alert.
3. Idle time became very large often reaching 1.0 indicating that there was no need for any teams during that week.
4. The entire time series became very erratic with long periods of low activity and then periods of high activity.
5. Run time for the model was reduced to one sixth of the time previously required.

Reducing the MTBF for all components to .1 of their original value caused basically the opposite effect. There was so much activity that the alert rate dropped to near zero. The conclusion reached was that the MTBFs had to be such that sufficient activity must occur to keep a minimum number of teams occupied each week but not so much activity that statistics and criterion variables were useless. The final figures employed were the original MTBFs increased by a factor of 2.0.

MTM (Average Number of Maintenance Teams Assigned)

The average number of teams assigned was tested and used as the basis for the TMP forecasting model. Originally the TMP forecast was based on the maximum number of teams used in the previous week; however, it was found that this forecast was unstable and fluctuated widely. The TMP forecast based on the average number closely approximated the MRP method. In addition, safety stock was added to each TMP forecast. An analysis was accomplished on the proper level of safety stock and it was found that 20% of the average for team one, 15% of the average for team two, and 5% of the average for the team three were the best levels of safety stock, of those investigated, for the TMP model. It was also found that in order to maintain a stable system each model must take into account the backlog of work to be accomplished. The decision rule was to eliminate all backlog in one week. Thus, each week the queue length (number of missile components waiting to be repaired by each team) was multiplied by the average repair time of 34 hours and that result was divided by 168 hours or one week. If a queue existed, this would show a negative number of teams on hand and would be used for the starting value in the gross-to-net calculation and thus be part of the new forecast.

XFIRE (The Number of Teams to be Fired)

If the average number of teams required in periods 8, 9, and 10 was negative, then that average would be subtracted from the order at period eight. However, in order to maintain the safety stock, the number of teams to be fired would be reduced by the safety stock percentages previously established.

The goal of this sensitivity analysis was to establish a "steady state" model which would operate within a relevant range. This goal was accomplished as can be observed by the results of Experiment 1.

After all exogenous variables were set and the initial values of endogenous variables were established, it was found that the combined effect of all variables required about 50 weeks to insure that the effects of start-up of the model were removed. Thus, the final program goes through an eight week start-up period (1,344 hours) before the first forecast is made and then forecasts are made for 50 weeks (8,400 hours) before data are collected on the performance of each forecasting method. Data are then collected for 104 weeks.

One final major problem occurred in analyzing the program and output. It was found that the time series had some amount of autoregression. Autoregression was suspected, as it should be in any simulation model and a test was made using the Box-Jenkins methodology.[5] The identification program of Box-Jenkins showed that the alert rate time series for the TMP model was correlated as follows:

	CORRELATION	STANDARD ERROR
1st difference	.33	.11
2nd difference	.20	.12
3rd difference	.09	.13
4th difference	.07	.13
5th difference	-.13	.13
6th difference	-.12	.13
7th difference	-.09	.13
8th difference	.02	.13

The series showed a definite wave pattern with at least a first degree autoregression and possibly second degree autoregression.

The series was a stable series, however (i.e., it did not drift up or down but was basically distributed around a constant average), so the only real problem exposed by the Box-Jenkins methodology was autoregression. The value to test for white noise[6] was 33.516 with 36

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[5]Dr. Richard E. Baker provided the technical materials and instruction for application of the Box-Jenkins methodology.

[6]White noise refers to a measure of dependence within the time series which can be attributed to random effects.

degrees of freedom. The Chi Square value for 36 degrees of freedom was 22.30 so again there was evidence of autoregression.

The solution was to use blocking[7] techniques to determine if an independently distributed series could be obtained. In this investigation blocking was attempted at one week intervals and the new series was analyzed by use of the Box-Jenkins program. This time it was found that the series was basically independent. The test for white noise was 15.561 compared to a Chi Square statistic of 22.30. The time series for each criterion variable was tested in a similar manner and it was found that the alert time series for TMP mentioned above had the most autoregression of any series. In fact, the alert series for MRP was initially independently distributed. Regardless of the initial distribution, blocking was consistently used for each criterion variable.

One minor problem was left due to the requirement for blocking. The power of the F-test was performed and it was found that a minimum of 31 observations would be required to insure a .05 level of significance. Since the sensitivity analysis required extending the start-up period to 58 weeks, a new run length was established at 162 weeks with 104 collectable data points or weeks. Even with blocking, there would be 52 independent data points remaining.

Experimental Results

Introduction

To aid in comparison of the manpower planning methods and in comparison

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[7]Blocking is a technique of removing dependence within a time series by including observations only at particular intervals.

[8]The power of the F-test was used to determine the size of the population required, given a sample variance and statistical significance level desired. The formula used was from Guenther, William C., Analysis of Variance, Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1964, p. 47.

of one experiment to another as much consistency as possible was maintained. For example, the same number of data points were collected in the same way, the same random number string was used for each run, and results were reported and displayed in the same manner.

The results were analyzed using SPSS (Statistical Package for the Social Sciences) Program T-TEST. This program compared results from the two experimental methods for each variable using pooled and separate variable t-tests. Additionally, Program T-TEST automatically used the F-test to compare the variances of the two variables considered. Figures 5, 6, and 7 show the results of the comparisons of MRP and TMP for each experiment. Differences between means and variances are shown by indicating levels of significance of .01 and .05. The sign showing a statistically significant difference was placed next to the "best value." The best value for alert rate would be the highest number of missiles on alert. For example, Figure 5 shows an average of 13.32 missiles on alert for the MRP condition and 13.53 missiles on alert for the TMP condition. No sign next to either value indicates no statistical difference at the .05 level or better. The best value for the remainder of the variables would be the lowest number. For example, the best value for the number of teams assigned would be the fewest number of teams assigned on the average. The best value for the waiting time would be the lowest average number of hours that components waited for the proper team. For idle time, the best value would be the lowest percentage of teams idle. Finally, for all variances, the best value would be the lowest standard deviation since that would indicate the value which was most consistent.

Experiment 1

The purpose of this experiment was to establish a base line with which to compare future experiments as well as to provide an initial comparison of MRP and TMP. Each forecasting method was required to forecast for the duration of the simulation run with no modifications to the configuration of the missile system.

First, a comparison was made between the data for the first 52 weeks and the data for the second 52 weeks to determine if there was a significant difference, over time, in any of the criterion variables. For example, the comparison was intended to determine if the alert rate changed significantly over the two-year period. It was found that all of the criterion variables were stable over time.

Next, a test was made for independent data as indicated in the sensitivity analysis and again it was found that for most of the criterion variables, blocking would be required. One week periods of blocking were sufficient.

Finally, the test for differences between MRP and TMP was made. Four additional criterion variables were added. They all measure the number of teams assigned since this figure is most directly related to manpower costs. They are ZMT1, ZMT2, ZMT3, and AMTOT or the number of teams of types one, two, three, and the total used. The two primary variables which were observed are Alert Rate and the Number of Teams Assigned. These will be placed first on all statistical tables followed by waiting time and finally idle time. Figure 5 shows the results of Experiment 1.

In summary, both models managed to keep about the same number of missiles on alert but MRP was better at reducing manpower costs. MRP, for all teams and the total number of teams, had significantly fewer teams assigned which also resulted in lower idle time. TMP, on the other hand, had components waiting a shorter amount of time for team three. At this point in the experimental sequence it can only be said that both

Results of Experiment 1

CRITERION VARIABLE	MEAN	STANDARD DEVIATION
ALERT RATE		
MRP	13.32	2.39
TMP	13.53	3.05
TOTAL NUMBER OF TEAMS		
MRP	34.37**	4.11**
TMP	48.42	14.39
NUMBER OF TEAM 1		
MRP	15.48*	3.64*
TMP	23.03	14.42
NUMBER OF TEAM 2		
MRP	9.44**	1.70**
TMP	12.11	3.28
NUMBER OF TEAM 3		
MRP	9.44**	1.69
TMP	13.27	1.92
WAITING TIME FOR TEAM 1		
MRP	15.77	29.81**
TMP	25.52	45.68
WAITING TIME FOR TEAM 2		
MRP	5.50	11.62
TMP	3.35	9.98
WAITING TIME FOR TEAM 3		
MRP	3.43	9.33
TMP	.05**	.29**
IDLE TIME TEAM 1		
MRP	.24**	.21*
TMP	.37	.31
IDLE TIME TEAM 2		
MRP	.30**	.24
TMP	.44	.21
IDLE TIME TEAM 3		
MRP	.37**	.26
TMP	.57	.17

* .05 significance level
** .01 significance level

Figure 5

methods keep the same number of missiles on alert (the primary objective) but that MRP is more cost effective. MRP had 29.02 percent fewer teams assigned on the average than TMP.

Note that four additional criterion variables were added: the number of teams of type one assigned, the number of teams of type two assigned, the number of teams of type three assigned, and the total number of teams assigned. These were added, even though other variables reflect the number of teams assigned, because manpower costs can be more directly calculated based on the number of teams assigned.

Experiment 2

The purpose of this experiment was to investigate the manpower methods under conditions of modifications to the configuration of the missile system. Three levels of modifications were examined independently. For the first modification a change was made to the MTBF (mean-time-before-failure) of component four (4). This was done by adding a routine to SUBROUTINE LOAD. After the initial load was accomplished, an event was programmed to return to SUBROUTINE LOAD at 14,784 hours into the simulation. This allowed 1,344 hours or 8 weeks for initialization, plus 50 weeks for start-up effects to be eliminated, and then 30 weeks into the actual data collection run for the modification to occur. The actual modification resulted in reducing the MTBF for component four (4) by 40%. Forty percent change in the MTBF was arrived at by sensitivity analysis. It was found changes of 10, 20, and 30 percent of the MTBF of components with large MTBF had negligible effects on the system. A change in 40% had a noticeable effect but if that change was positive, the effects were washed out by the fire rule. This was true since increases in MTBF results in reduced manpower requirements and therefore overages in manpower which the fire rule eliminates. The results of this experiment are shown in Figure 6.

Results of Experiment 2

CRITERION VARIABLE	MEAN MOD1	MEAN MOD2	MEAN MOD3	STANDARD DEVIATION MOD1	STANDARD DEVIATION MOD2	STANDARD DEVIATION MOD3
ALERT RATE						
MRP	11.48	12.38	13.07	2.55	2.45	2.44
TMP	11.96	13.09	13.67	2.77	3.04	2.87
TOTAL NUMBER OF ALL TEAMS						
MRP	37.50**	34.12**	32.96**	5.06**	3.57**	3.75**
TMP	49.87	40.42	47.40	13.34	15.63	14.19
NUMBER OF TEAM 1						
MRP	17.94**	16.15**	16.58**	3.71**	3.22**	3.43**
TMP	23.21	24.38	23.10	12.05	15.36	14.21
NUMBER OF TEAM 2						
MRP	9.71**	9.34**	7.77**	2.06**	1.97**	1.52**
TMP	12.67	11.50	10.48	3.03	2.91	2.97
NUMBER OF TEAM 3						
MRP	9.85**	8.62**	8.62**	2.10	1.32**	1.43*
TMP	13.98	13.54	13.83	2.71	2.25	2.01
WAITING TIME FOR TEAM 1						
MRP	7.47**	18.42	9.38	13.74**	32.36**	18.84**
TMP	19.40	33.47	23.20	27.38	60.28	47.69
WAITING TIME FOR TEAM 2						
MRP	6.91	6.18	4.96	11.23	10.32	9.80
TMP	1.24**	2.70	2.13	4.76**	8.03	5.39**
WAITING TIME FOR TEAM 3						
MRP	2.20	3.43	4.68	3.90	5.15	7.99
TMP	.08**	.08**	.03**	.33**	.39**	.11**
IDLE TIME TEAM 1						
MRP	.23**	.21**	.27	.18**	.20**	.19**
TMP	.33	.37	.36	.30	.31	.30
IDLE TIME TEAM 2						
MRP	.28**	.33*	.31**	.23	.30	.27
TMP	.49	.44	.46	.21	.21*	.23
IDLE TIME TEAM 3						
MRP	.32**	.29**	.31**	.25	.25	.25
TMP	.53	.56	.57	.20	.18*	.20

* .05 significance level
** .01 significance level

Figure 6

The results of the first modification of Experiment 2 show that there was no significant difference in alert rate or variance in alert rate and again MRP maintained a comparable alert rate as TMP with significantly fewer teams assigned. There also were some differences between MRP and TMP in waiting time. The differences were significant at the .01 level but they were mixed. MRP had a lower waiting time and variance in waiting time for team one while TMP showed a lower waiting time and variance in waiting time for teams two and three. Since the change in MTBF affected only team one, it could be said that MRP did a better job of responding to the modification but results are not conclusive. The important result is that MRP proved better on keeping fewer teams assigned for all seven of the manpower cost variables (i.e., the number of teams assigned (4) and idle time (3)) while maintaining the same alert rate. Additionally, MRP consistently performed better with team one, the long lead-time team.

Experiment 2 was compared with the base line results of Experiment 1. Most variables were unchanged by the modification but for both manpower methods, MRP and TMP, the alert rate was significantly lower at the .01 level.

The <u>second modification</u> required a change in the repair time for a component. Again, the programmed modification was set up in SUBROUTINE LOAD for the same time period (30 weeks into the data collection period of 104 weeks). This time a 40% increase was made to the repair time for component four (4). The logic for choosing a 40% increase was the same as for the MTBF modification except that here a decrease in repair time would cause a reduction in manpower requirements and therefore an overage which would be eliminated by the fire rule. So, an increase in repair time was used for the modification. Note that in both modification 1, a change in the MTBF, and modification 2, a change in the repair time, the TMP model in no way adjusted for the modification prior to its implementation. The MRP model, on the other hand, incorporated the anticipated modification into its master schedule (anticipated manpower requirements matrix).

The results of modification 2 of Experiment 2 are thoroughly mixed and are shown in Figure 6. There was no difference in the alert rate and the waiting times for teams one and two. MRP had the lowest variability in waiting time for team one and TMP had the lowest waiting time and variability for team three. MRP had the lowest idle time and the lowest number of teams assigned but TMP had the lowest variability in idle time for teams two and three. These results basically indicate that TMP consistently had a higher amount of idle time than MRP. The same general conclusion can be drawn here as the one made from the first modification--that MRP maintained the same alert rate with a fewer number of teams assigned.

Again Experiment 2 was compared with Experiment 1 and the results showed little difference except that there was a significantly lower alert rate in Experiment 2 than in Experiment 1.

The third modification for Experiment 2 was of a different nature than the first two. It required a modification that changes the time required to repair a component. In this case, the usual programmed modification was included in SUBROUTINE LOAD and the modification was permanently implemented at the appropriate time (30 weeks into the data collection period of 104 weeks). The same adjustments to the master schedule were used for MRP in this modification as for the other two. However, TMP had an additional routine added. Since it was determined that this modification would be a change from a requirement for an Electro-mechanical team (team 2) to a purely Missile Electrical team (team 1), then the TMP model would be aware that a team change would be required by the modification. Additionally, since the time of the modification was known, then planning would be relatively straightforward. In the TMP routine which determined manpower requirements, an up-to-date analysis was made each week to determine the approximate number of teams which would be required to include the new component (number 9) for team one and the number of teams to be reduced for team two. This was evidently very effective since a comparison of the base line Experiment 1 with Experiment 2, modification 3, showed little difference either for MRP or TMP.

The results were about the same as for Experiment 2, modification 2, in that they were mixed. The alert rate was not different and waiting time was mixed as in modification 2. Idle time showed that MRP maintained lower idle time for teams two and three and lower variance for team one, and that TMP maintained lower variance in idle time for team one. MRP also required fewer teams of each type and maintained a lower variance in the number of teams required than TMP. In fact, MRP had over 30% fewer teams assigned on the average than TMP.

In summary, the results of Experiment 2 demonstrated that the MRP method of manpower planning was superior. This experiment did show that MRP maintained an alert rate that was not significantly different from TMP (either in mean or variance) with a fewer number of teams assigned. Since idle time was lower and in some cases waiting time was lower, it would hint that MRP maintained a more exact number of teams assigned at the right time and that TMP maintained a consistently higher number of teams assigned.

Experiment 3

The purpose of this experiment was to investigate the two alternative manpower concepts under conditions of simultaneous modifications to the configuration of the missile system. This experiment was conducted at two levels: one simultaneous modification and two simultaneous modifications. A simultaneous modification is one in which all three variables of one component change at the same time. This is when the MTBF, repair time, and the team designated to repair that particular component all change. For the first level the MTBF of component 9 was reduced by 40% at 30 weeks into the data collection part of the simulation run as in Experiment 2. At the same time, the repair time for component 9 was increased by 40% and the team assignment was changed from team two to team one.

For the TMP model these changes were accomplished in SUBROUTINE LOAD for all three variables at 30 weeks; and as in modification three of Experiment 2, the team assignment change was preplanned in the TMP manpower requirements subroutine. For MRP, the entire modification was carried out in the master schedule routine and program modification in SUBROUTINE LOAD was not required. This included forecasting manpower needs and permanently modifying the system.

The results are shown in Figure 7 under the column labeled EXP 3-1. MRP demonstrated superiority in the primary criterion variables: the alert rate, variance in alert rate, the number of teams and variance in teams one and two, and the total number of teams assigned. Also waiting time and variance in waiting time for team one and two were significantly better for MRP at the .01 level. TMP showed a lower waiting time and variance in waiting time for team three. MRP had lower idle time for team three and lower variance in idle time for team one. Most important, MRP showed either a lower number of teams assigned or lower variance in the number of teams assigned for each team type while maintaining a

Results Of Experiments 3 and 4

CRITERION VARIABLE	MEAN EXP3-1	MEAN EXP3-2	MEAN EXP4	STANDARD DEVIATION EXP3-1	STANDARD DEVIATION EXP3-2	STANDARD DEVIATION EXP4
ALERT RATE						
MRP	11.46**	9.92*	11.46**	3.70*	4.03	3.70**
TMP	8.42	8.20	7.27	5.13	4.58	5.65
TOTAL NUMBER OF ALL TEAMS						
MRP	31.27	34.96	31.27	5.92**	7.21**	5.92**
TMP	34.88	36.29	33.98	17.78	18.29	17.21
NUMBER OF TEAM 1						
MRP	14.81	15.37	14.81	4.68**	5.83**	4.68**
TMP	11.63	11.38	10.50*	13.34	15.20	14.31
NUMBER OF TEAM 2						
MRP	8.60	9.56	8.60	3.44**	3.71**	3.44**
TMP	10.63	11.75	11.02	10.31	11.12	10.12
NUMBER OF TEAM 3						
MRP	7.87**	10.04**	7.87**	2.69	2.79	2.69
TMP	12.62	13.15	12.46	3.08	2.72	3.35
WAITING TIME FOR TEAM 1						
MRP	12.82**	32.39**	12.82**	19.41**	42.85**	19.41**
TMP	108.48	114.20	144.47	158.76	164.43	171.28
WAITING TIME FOR TEAM 2						
MRP	15.30**	25.59	15.30**	17.89**	50.65	17.89**
TMP	47.94	43.49	56.33	55.99	55.21	71.59
WAITING TIME FOR TEAM 3						
MRP	11.95	4.17	11.95	13.63	7.34	13.63
TMP	.36**	.31**	.33**	1.09**	1.13**	.96**
IDLE TIME TEAM 1						
MRP	.25	.23	.25	.21**	.25	.21**
TMP	.24	.20	.22	.32	.30	.31
IDLE TIME TEAM 2						
MRP	.26	.26	.26	.27	.24	.26
TMP	.22	.22	.25	.28	.27	.29
IDLE TIME TEAM 3						
MRP	.31**	.34**	.31**	.24	.24	.24
TMP	.53	.52	.52	.24	.17*	.20

* .05 significance level
** .01 significance level

Figure 7

significantly better alert rate.

For the second level of this experiment, the one designated as EXP 3-2 in Figure 7, MRP also demonstrated a higher alert rate and lower waiting time and variance in waiting time for team one. This level consisted of two simultaneous modifications to the missile system configuration. The first modification was exactly the same as for level one and the second followed in five weeks and was implemented in exactly the same way as for level one. The first simultaneous modification affected missile component nine and the second simultaneous modification affected component seven. The only difference in logic was that for the second modification the MTBF was reduced by 75%.

TMP again demonstrated a lower waiting time and variance in waiting time for team three. Idle time was basically the same for each model with MRP producing a lower idle time for team three. Finally, MRP showed a lower number of teams assigned or lower variance in the number of teams assigned for each type of maintenance team.

Both levels of Experiment 3 were compared with Experiment 1 (MRP Experiment 1 vs MRP Experiment 3 and TMP Experiment 1 vs TMP Experiment 3). The results showed that there was a significant difference between the performance of each method under steady state and with simultaneous modifications.

In summary, Experiment 3 demonstrated that the MRP model was superior to the TMP model. MRP maintained a higher alert rate with a more exact number of teams assigned.

Experiment 4

The purpose of this experiment was to test the performance of the two alternative manpower methods under the condition which sometimes exists in military systems when emergency modifications are required.

For this experiment one simultaneous modification was chosen to be implemented at the 30th week of the data collection run. This modification differs from previous ones in that only one week's warning was given to each model and results were observed as before. TMP had one week to prepare for the change in team assignment as before and MRP had one week in which to adjust its master schedule. The results showed that MRP was far superior to TMP in adjusting to such an emergency change. The alert rate, waiting time for all teams, and the variances for all of these variables were significantly better for MRP than for TMP. MRP had a lower idle time for team three, variance in idle time for team one, and a lower number of team three assigned. MRP also showed a lower variance in teams one, two, and the total number of teams assigned. On the other hand, TMP showed a significantly (.05) lower number of team one assigned. This was probably to its detriment since the alert rate was significantly lower and waiting time for team one was significantly higher.

Use of Blocked Data Compared to Original Data

An interesting result to note comes from the data analysis technique employed. It is an accepted fact that if one is to analyze data for significant differences between the means of two populations by usual methods (such as the t-test), independence between data points is a necessity. Testing a time series from a simulation model for independence is not an easy task for the novice. One must search for the right technique (such as the complex but powerful Box-Jenkins methodology) and apply that technique.

Many simulation researchers follow Conway's (1963, p. 53) advice and test for independence, then use a blocking technique if necessary, and again test for independence. With this approach, the researcher hopes at some point in time, to find a string of data points which are basically independent. Results of data analysis from this investigation indicate that independence is not critical and that the usual t-test is sufficient. This was verified by comparing results from the blocked data, which was proven independent by the identification program from Box-Jenkins methodology, to results from the original data, which had first degree of autoregression, with no significant difference. This was accomplished using 44 separate variables, independently tested, with no significant difference in the results between the original and blocked data.

In summary, this is not to say that the independence assumption is not valid but that for this variable-time simulation model it does not make any difference.

Summary

The MRP model demonstrated superiority in Experiments 1 and 2 by maintaining the same alert rate with fewer maintenance teams, in Experiment 3 by maintaining a higher alert rate with a more exact number of teams, and in Experiment 4 by maintaining a higher alert rate with less waiting time. Experiment 3 is significant because it shows that TMP had a fewer number of teams assigned in some cases but waiting time for those teams was exceptionally high indicating that there were too few teams assigned. One last point is that MRP was usually more consistent than TMP (i.e., lower variance in each variable at the .01 significance level) in maintaining the alert rate, the same number of teams assigned, and waiting time. Note that all variables are interrelated and results cannot be interpreted based on one variable alone. The next chapter will show an interpretation of the results presented in this chapter.

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

Four experiments were conducted to investigate two alternative manpower planning methods under differing environmental conditions. The first method was based on traditional extrapolation techniques currently being used in many firms and throughout the Air Force. The second method applied the concept of Material Requirements Planning (MRP), a forward looking method which devises a master schedule and from that point on the system is deterministic. The specific environment chosen for the comparison was the "high technology" environment of the USAF Minuteman Intercontinental Ballistic Missile maintenance system. This system currently uses the traditional manpower extrapolation technique simulated in the first manpower model mentioned above.

The method of comparison was a simulation model, which is similar to the real system in that missile components fail, in some cases taking the missile off alert. Maintenance teams are subsequently dispatched to repair that failure, and the missile is again operational. The experiments were designed to increase the complexity of the environment in which the manpower methods had to operate by modifying the configuration of the missiles. This was done by sequentially modifying system elements to approximate real world conditions.

The first experiment established a base line with which to compare the effects of additional experiments. This initial experiment provided the first comparison of the material requirements planning method (MRP) with the traditional extrapolation manpower method (TMP). Both methods performed satisfactorily, but MRP maintained the same alert rate as TMP with fewer teams of each type. The real test of each method comes through the analysis of alert rate, the number of teams used, and waiting time for teams. Since alert rate is related to the number of priority one and two components down and waiting, the waiting time (the time that missile components are down and waiting for a particular team) becomes a measure of alert effectiveness to a point. All three of these criteria are necessary to evaluate the real world situation since it is possible to have a high alert rate and low waiting time simply by having too many teams assigned. In the case of Experiment 1, the results are mixed but MRP was superior since it used about 30% fewer teams and therefore was more cost-effective. Additionally, MRP demonstrated a predictive capability which becomes obvious with better forecast for the long lead time required for team one.

Experiment 2 had about the same results as Experiment 1 with MRP performing a little better relative to TMP in Experiment 2. It appears that the magnitude of the modifications by themselves was not sufficient to seriously impact the performance of either method. There were 30 missiles and 10 components per missile resulting in 300 components. Since any modification affected only a portion of the system, it tended to be absorbed into the complexities of the system. It is unlikely that only one of the three variables concerned (MTBF, repair time, team assignment) would be affected by a real system modification, but this Experiment 2 was necessary to determine the individual effects of the three types of system modification Individually, MTBF had the greatest impact on system performance when compared with Experiment 1, with repair time having a milder impact, and the effects of a team change barely noticeable.

The synergistic effect of the three types of system modification on system performance was demonstrated in Experiment 3. With all three types of modification impacting the same component at the same time, the first opportunity was provided to examine the responsiveness and extent of the performance of each manpower planning method. The combined effects of simultaneous modification produced significant results. It was evident, especially when two simultaneous modifications were implemented five weeks apart, that the traditional manpower method tended to have too many of team three assigned (team three required 10 weeks lead time to procure) and too few of team one (team one required 30 weeks to procure). Even though the modifications did not directly affect team three, the effects on teams one and two caused additional turbulence in the environment making the forecast for team three more complex.

The TMP model showed lower waiting time for team three but significantly higher idle time, again demonstrating an over-manning condition. This extrapolation model also showed about the same idle time for teams one and two but significantly higher waiting times for those teams. This indicates that the teams were assigned at the wrong times.

Experiment 4 was not necessarily more complex than Experiment 3. In fact, the modification itself was the same as one of the simultaneous modifications of Experiment 3, but it introduced great uncertainty in the environment. Knowledge of the modification was available only one week in advance. When the modification was implemented, waiting lines built up for team one, and team two was over-manned for both models. MRP responded more quickly and moved toward the "right" number of teams of each type. This type of modification is not unlike the real system although the real system often must respond to many types of modifications at one time. Among all the experiments, MRP achieved a higher differential in alert rate in Experiment 4.

In summary, TMP is adequate (in terms of alert rate) in a relatively stable environment but not as cost effective as MRP. The more complex the environment becomes; i.e., the more personnel needs change (in quality or quantity), the less effective the extrapolation model becomes. In fact, when the environment becomes uncertain; i.e., when unplanned changes occur on short notice, TMP becomes very inadequate. MRP, on the other hand, responds better in all types of environment changes. It does not do as well in a turbulent environment as in a stable environment, but it does significantly better than the TMP method. MRP tends to have the fewest number of teams assigned at the right time thereby maintaining the highest alert rate and making the best use of available capacity. On the other hand, MRP requires a significant initial investment in time and money plus it requires continued support for proper reporting of events (i.e., tasks completed, time required per task, etc.) to provide the most accurate data base for forecasting.

Conclusions

The MRP manpower planning method conceptualized and implemented in this investigation demonstrated superiority over the extrapolation method which was an operationalization of the currently used method. The MRP method demonstrated an ability to respond to complex modifications and performed better than TMP on all primary criterion variables. More complex environments make little difference to the MRP model as long as the master schedule is built on reliable information. Even if such information were available to the TMP model, it could not be used.

This benefit from the MRP model makes it a cost effective tool for managers of complex or high technology systems. Experiment 1 showed that even systems which are not so complex might benefit from MRP on a cost effective basis. However the question still remains whether the initial investment would be worth the benefits derived. MRP is a self-improving system. It requires an initial investment in the data base and input information before implementation. Once operational, an MRP system can record and update relevant manpower statistical variables from which more exact manpower forecasts can be made.

The MRP model also demonstrated that it not only has the fewest number of teams to perform the objective but that it has the right teams at the right time. This reinforces the MRP objective stated by Orlicky at the American Institute for Decision Sciences (AIDS) meeting in Cincinnati in 1975, to be "always working on the right job at the right time." If employees are not working on the right job at the right time, then capacity is being misused. Capacity utilization for this investigation was measured by idle time for each type of team, and MRP maintained lower idle time overall.

This aspect should be very attractive to managers: MRP enables them to forecast manpower needs so that manpower will be most fully utilized. The proof of the MRP method comes when it demonstrates a capability of working on the right job at the right time. This means to have the properly skilled technician available when needed. Such a system would identify and eliminate bottlenecks, peaks and valleys caused by multiple impacts to the system requirements. This also would reduce the organizational behavior problems caused by under-manning and over-manning. There are a multitude of additional administrative and operational benefits from MRP (i.e., capacity utilization, team structure, career development, cost data, etc.).

This investigation shows that the simulation method is a valuable technique for analyzing systems as complex as manpower planning methods. It is, of course, not simple to approximate the utility function or decision making function of the manager; but, up to the point of the decision, the simulation technique provides a reliable, versatile, and useful technique for examining various concepts. When alternative policies and future directions for this research are considered, the versatility of simulation becomes apparent.

Some intriguing next steps in this research may be to experiment with alternative modifications to the system, to make the system itself more complex by adding additional missile components, equipment, and vehicles, or to compare MRP with a multitude of other techniques for manpower planning. Additional accuracy may be gained from the MRP method by "fine tuning" the simulation model. This may include a small margin of safety stock built into the MRP forecast. Such a change is supported by the fact that MRP is more conservative in manpower utilization than the extrapolation method and a slight increase in manpower may produce additional benefits in the alert rate of reductions in waiting time.

Decision rules such as these can easily be tested in a simulated MRP system. This aspect of MRP provides the capability of testing various management decisions prior to implementation of those decisions.

The capability of MRP to consider future system configurations would provide the opportunity to modify the data base of an existing MRP system to determine the manpower needs of a proposed missile system thereby identifying future costs for personnel and associated equipment. Such "forward looking" may identify critical shortages of certain technical skills which cannot be filled by hiring or training. In such a case, the system configuration may be redesigned to utilize alternative skills.

The effects on manpower requirements due to personnel oriented programs can be evaluated in the same manner. For example, in job enrichment/job enlargement type programs, where the task to be considered for a particular job can be identified, the problem of analysis is similar to MOD 3 of Experiment 2. The MRP system would allow switching many tasks between various teams simultaneously. Of course, the more specifically the task is defined the more completely the results can be analyzed. Similarly, the impact of a new missile component on manpower requirements can be analyzed. One anticipated modification can be analyzed independently from other effects and therefore the desirability of benefits to the system can be compared to the costs in manpower. It may be that the modification may add little to the system and be quite costly, a fact that would be very important to the decision maker.

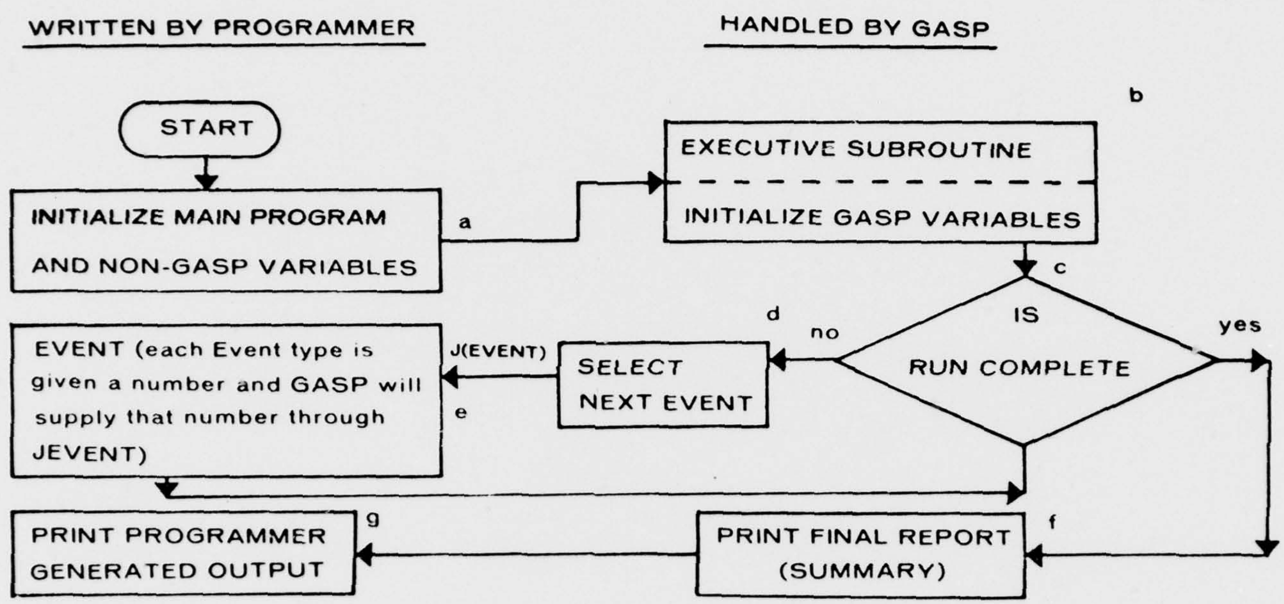
As such experimentation progresses toward the "real world," comparisons of the model against actual data may become possible and from that, a full implementation of the MRP system may result. If the real world results are as obvious as the simulation results, then MRP should become a very powerful cost effective management tool for manpower planning that will produce benefits in the short-run as well as over the long-run.

APPENDIX A

FLOW CHARTS

1. General GASP II Flow Chart
2. Programmer Written Flow Charts

GENERAL PROGRAM FLOW - GASP II



JEVENT

1 FAIL

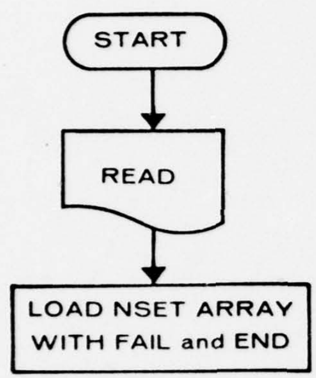
2 FIXED

3 FORCST

4 LOAD

5 ENDSIM

INITIALIZE AND LOAD



READ = PRIOR(K) - Maintenance priority for component K.

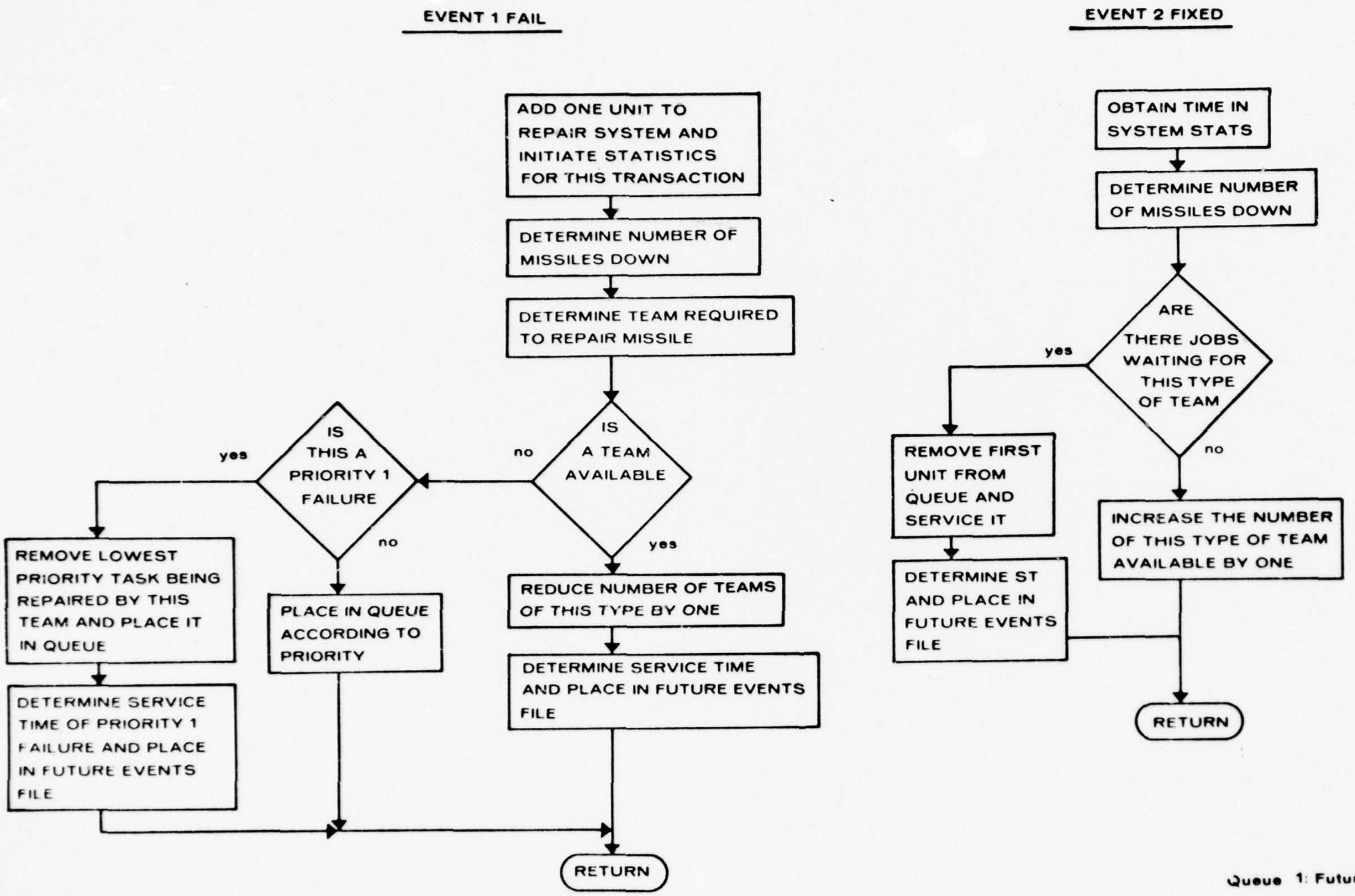
MTEAM(K) - Team required to repair component K.

ZMEAN(K) - Mean failure time for componet K.

REPAIR(K) - Average time required to repair componeni K.

FAIL - Time before failure of component K on missile J.

END - End of simulation run.

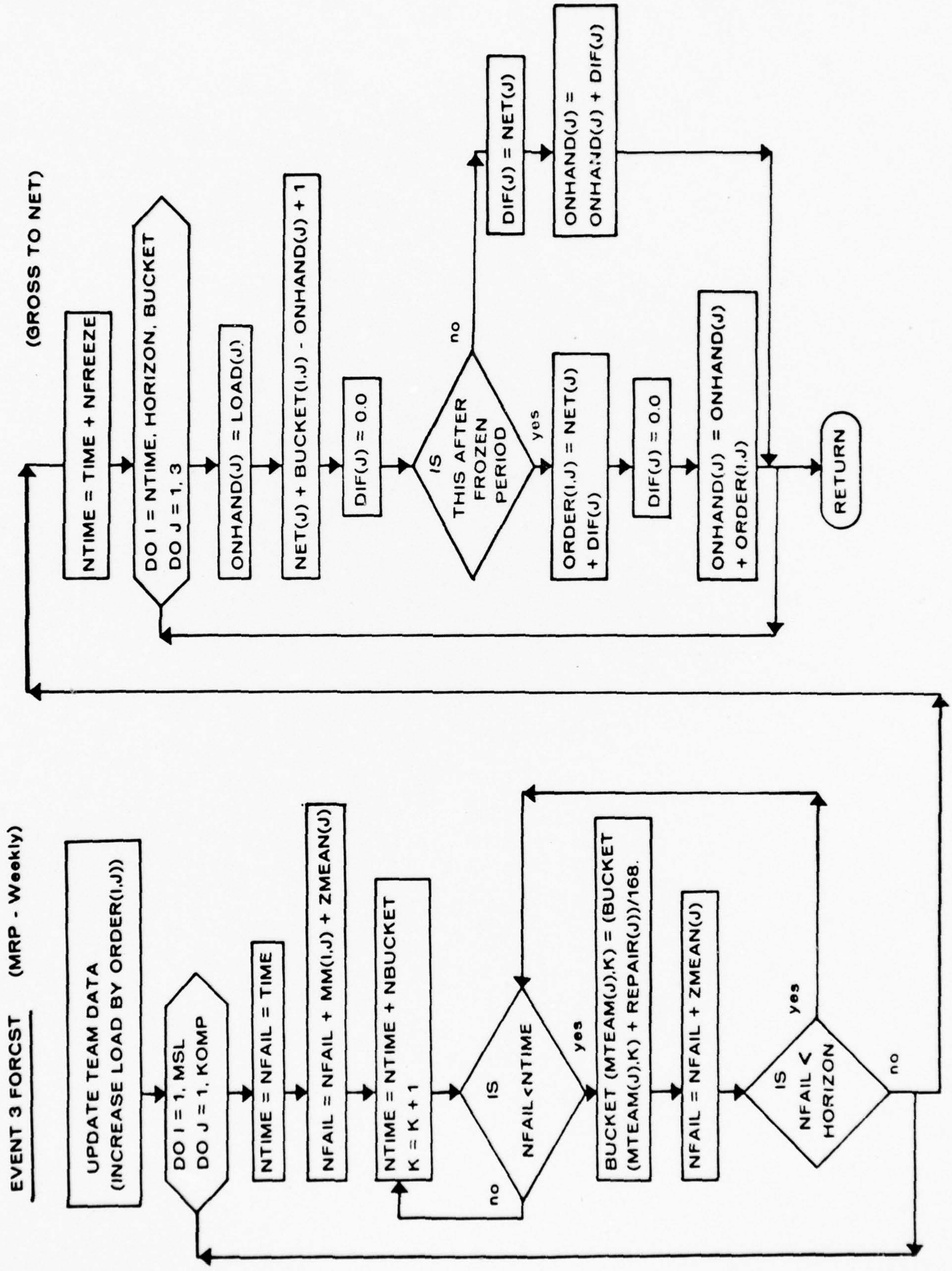


Queue 1: Future events file

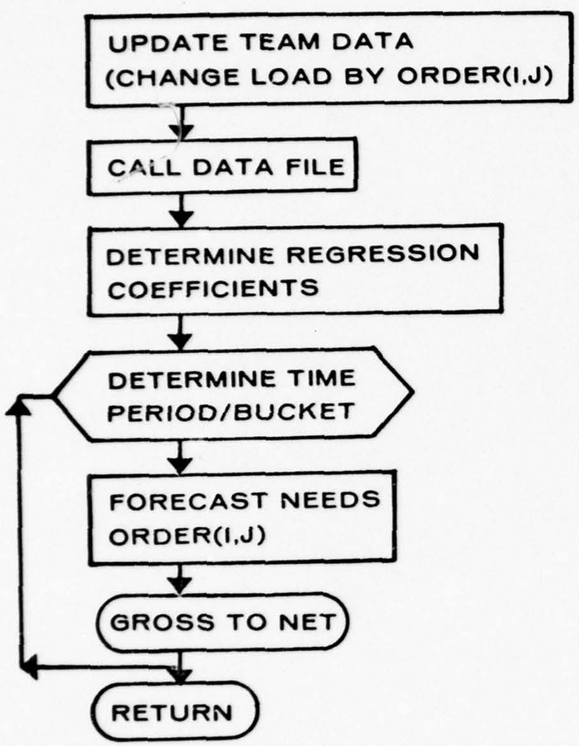
Queue 2: Components waiting for team 1

Queue 3: Components waiting for team 2

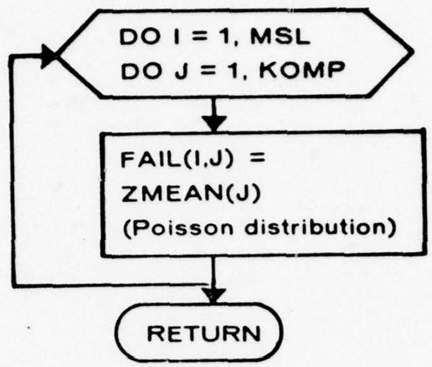
Queue 4: Componets waiting for team 3


EVENT 3 FORCST (MRP - Weekly)
UPDATE TEAM DATA (INCREASE LOAD BY ORDER(I,J))
DO I = 1, MSL
DO J = 1, KOMP
NTIME = NFAIL = TIME
NFAIL = NFAIL + MM(I,J) + ZMEAN(J)
NTIME = NTIME + NBUCKET
K = K + 1
IS NFAIL<NTIME
yes
no
BUCKET (MTEAM(J),K) = (BUCKET (MTEAM(J),K) + REPAIR(J))/168.
NFAIL = NFAIL + ZMEAN(J)
IS NFAIL < HORIZON
yes
no
(GROSS TO NET)
NTIME = TIME + NFREEZE
DO I = NTIME, HORIZON, BUCKET
DO J = 1, 3
ONHAND(J) = LOAD(J)
NET(J) + BUCKET(I,J) - ONHAND(J) + 1
DIF(J) = 0.0
IS THIS AFTER FROZEN PERIOD
no
yes
DIF(J) = NET(J)
ONHAND(J) = ONHAND(J) + DIF(J)
ORDER(I,J) = NET(J) + DIF(J)
DIF(J) = 0.0
ONHAND(J) = ONHAND(J) + ORDER(I,J)
RETURN

EVENT 3 FORCST (TMP - Weekly)



EVENT 4 LOAD



MSL = 50 Missiles
KOMP = 10 components

APPENDIX B

PROGRAM LISTINGS

1. Complete MRP Program Listing

2. SUBROUTINE FORCST for TMP

```
**********************************************************************************

DAWSAEN    DROP B
SEQ        BIN 88

                              DDDDDDD       AA       WW      WW   SSSSSS      AA
                              DD    DD     AAAA      WW      WW  SS    SS    AAAA
                              DD    DD    AA  AA     WW      WW  SS         AA  AA
                              DD    DD   AA    AA    WW      WW   SSSSSS   AA    AA
                              DD    DD   AA    AA    WW  WW  WW        SS  AA    AA
                              DD    DD   AAAAAAAA    WWWWWWWWWW        SS  AAAAAAAA
                              DD    DD   AA    AA    WWW    WWW        SS  AA    AA
                              DD    DD   AA    AA    WW      WW  SS    SS  AA    AA
                              DDDDDDD    AA    AA    W        W   SSSSSS   AA    AA

                                  ************************************************
                                  ************************************************


DAWSAEN. 76/05/18. NDIANA UNIVERSITY - LEVEL 9.

09.21.16.JOB READ AT  09.21.15. 76/05/18.
09.21.16.DAW,T430,DRU.
09.21.16.ACCOUNT,7016,.
09.21.16.PAGES=100.
09.21.16.CARDS=110.
09.21.16.GET(MRP5)
09.21.17.GET(TAPE60=COM3)
09.21.17.ROUTE(OUTPUT.WASTE,EJ,L=WCC)
09.21.18.GET(TAPE5=GASPBIN)
09.21.20.FTN(R=0,I=MRP5)
09.22.09.      5.029 CP SECONDS COMPILATION TIME
09.22.09.LOAD(TAPE5)
09.22.10.LGO.
10.15.17.STOP
10.15.18.REWIND,TAPE30.
10.15.20.COPYSBF(TAPE30,OUTPUT)
10.15.20. END OF INFORMATION ENCOUNTERED.
10.15.20.CP       3678    SEC.
10.15.20.CP    246.700    SEC.
10.15.20.CM      1.381    KWH.
10.15.20.MS      4.784    KPR.
10.15.20.CM      4.975    MWS.
10.15.20.BU      5.705


    76/05/18. 10.18.41.

**********************************************************************************
```

```
      PROGRAM MANPWR(INPUT,OUTPUT,TAPE60,TAPE61=OUTPUT,TAPE20,TAPE30,
     1TAPE40)
      COMMON /LUNS/ LUCDR,LUPTR,LUPCH
      COMMON ID,IM,INIT,JEVENT,JMONIT,MFA,MSTOP,MX,MXC,NCOLCT,NHISTO,
     1NOQ,NORPT,NOT,NPRAMS,NRUN,NRUNS,NSTAT,OUT,SCALE,SEED,TNOW,
     2TSTART,TSTOP,MXX
      COMMON ATTRIB(8),ENQ(15),INN(15),JCELLS(5,22),KRANK(15),MAXNQ(15),
     1MFE(15),MLE(15),NCELLS(5),NQ(15),PARAMS(20,4),QTIME(15),
     2SSUMA(25,5),SUMA(25,5),MLC(15),NSET(10,550)
      COMMON  XISYS(4),TISYS(4),PRIOR(10),MTEAM(10),ZMEAN(10),REPAIR(10)
     1,MT(3),MTA(3),MSL,KOMP,MSL1,ATVL,OT,XIDLE(4),MISA(50),XMISA,
     2NORDER(50,3),MM(50,10),BUCKET(50,3),ONHAND,NBUCK,NET,DIF
     3,NFREZE(3),MTM(3),MTU(20,3),XMTU(12,3),YBAR(3),A(3),B(3)
     4,ISAMP,XTX,XTM,XWA(3),XWM(3),XWT(3),XDT(3),XDM(3),XDL(3),ZMT(4)
      REAL MT
      REAL MTM
      LUCDR=INPUT(60,20)
      LUPTR=61
C  THIS CHANGE CHANGES THE MTBF FOR COMP 7 FROM 80. TO 800.
C  THIS CHANGE LEAVES PRIORITY 2 COMPONENTS ON ALERT WHILE WAITING
C  THIS CHANGE INCORPORATES ALL OF THE RECENT SUGGESTIONS BY DR.
C  FIRE RULE:50 PERIOD START-UP PAST INIT STAGE:FORECAST BASED ON AVERAGE
      MSL=30
      KOMP=10
      ATVL=2.5
      OT = 0.5
      NFREZE(1)=30
      NFREZE(2)=20
      NFREZE(3)=10
C  SET INITIAL MAINTENANCE LOADINGS AND STATISTICS VARIABLES
      DO 3 I=1,3
      MT(I) = 0
      MTM(I)= 0
      XIDLE(I)=0.0
      XISYS(I)=0.0
      TISYS(I)=0.0
      XWA(I)=0.0
      XWM(I)=0.0
      XWT(I)=0.01
      XDT(I)=0.0
      XDM(I)=0.01
      XDL(I)=0.0
      ZMT(I)=0.0
      K=NFREZE(I)+1
      DO 1 J=1,K
      BUCKET(J,I)=0.0
      NORDER(J,I)=0
    1 CONTINUE
      DO 2 K=1,20
      MTU(K,I)=5
      X=RAN(0)
    2 CONTINUE
    3 CONTINUE
      ONHAND=XNET=DIF=0.0
      NBUCK = 168
```

```
      MTA(1)=11
      MTA(2)=13
      MTA(3)=22
      XIDLE(4)=0.0
      XISYS(4)=0.0
      TISYS(4)=0.0
      ZMT(4)=0.0
C INITIALIZE THE NUMBER OF MISSILES ON ALERT
      XMISA = MSL
      XTX=XTM=0.0
C  LOAD MAINTENANCE TEAM PRIORITY, TEAM REQUIRED TO REPAIR COMPONENT, MEAN TIME
C  BEFORE FAILURE, AND MEAN REPAIR TIME PER COMPONENT.
      PRIOR(1)=PRIOR(2)=PRIOR(3)=1.
      PRIOR(4)=PRIOR(5)=PRIOR(6)=2.
      PRIOR(7)=PRIOR(8)=PRIOR(9)=PRIOR(10)=3.
      MTEAM(1)=MTEAM(4)=MTEAM(5)=1
      MTEAM(3)=MTEAM(7)=MTEAM(9)=MTEAM(10)=2
      MTEAM(2)=MTEAM(6)=MTEAM(8)=3
      ZMEAN(1)=400.
      ZMEAN(2)=220.
      ZMEAN(3)=160.
      ZMEAN(4)=280.
      ZMEAN(5)=1800.
      ZMEAN(6)=1200.
      ZMEAN(7)=800.
      ZMEAN(8)=180.
      ZMEAN(9)=780.
      ZMEAN(10)=240.
      REPAIR(1)=74.
      REPAIR(2)=22.
      REPAIR(3)=12.
      REPAIR(4)=68.
      REPAIR(5)=10.
      REPAIR(6)=8.
      REPAIR(7)=18.
      REPAIR(8)=13.
      REPAIR(9)=26.
      REPAIR(10)=9.
      CALL GASP
      STOP
      END
```

```
      SUBROUTINE EVENTS(IX)
      COMMON /LUNS/ LUCDR,LUPTR,LUPCH
      COMMON ID,IM,INIT,JEVENT,JMONIT,MFA,MSTOP,MX,MXC,NCOLCT,NHISTO,
     1NOQ,NORPT,NOT,NPRAMS,NRUN,NRUNS,NSTAT,OUT,SCALE,SEED,TNOW,
     2TSTART,TSTOP,MXX
      COMMON ATTRIB(8),ENQ(15),INN(15),JCELLS(5,22),KRANK(15),MAXNQ(15),
     1MFE(15),MLE(15),NCELLS(5),NQ(15),PARAMS(20,4),QTIME(15),
     2SSUMA(25,5),SUMA(25,5),MLC(15),NSET(10,550)
      COMMON  XISYS(4),TTSYS(4),PRIOR(10),MTEAM(10),ZMEAN(10),REPAIR(10)
     1,MT(3),MTA(3),MSL,KOMP,MSL1,ATVL,OT,XIDLE(4),MISA(50),XMISA,
     2NORDER(50,3),MM(50,10),BUCKET(50,3),ONHAND,NBUCK,NET,DIF
     3,NFREZE(3),MTM(3),MTU(20,3),XMTU(12,3),YBAR(3),A(3),B(3)
     4,ISAMP,XTX,XTM,XWA(3),XWM(3),XWT(3),XDT(3),XDM(3),XDL(3),ZMT(4)
      WRITE(40,98)IX
   98 FORMAT(2X,*THE FOLLOWING EVENT OCCURRED DURING DEBUGGING*,I5)
      GO TO(1,2,3,4,5),IX
    1 CALL FAIL
      RETURN
    2 CALL FIXED
      RETURN
    3 CALL FORCST
      RETURN
    4 CALL LOAD
      RETURN
    5 CALL ENDSIM
      RETURN
      END
```

```
      SUBROUTINE FAIL
      COMMON /LUNS/ LUCDR,LUPTR,LUPCH
      COMMON ID,IM,INIT,JEVENT,JMONIT,MFA,MSTOP,MX,MXC,NCOLCT,NHISTO,
     1NOQ,NORPT,NOT,NPRAMS,NRUN,NRUNS,NSTAT,OUT,SCALE,SEED,TNOW,
     2TSTART,TSTOP,MXX
      COMMON ATTRIB(8),ENQ(15),INN(15),JCELLS(5,22),KRANK(15),MAXNQ(15),
     1MFE(15),MLE(15),NCELLS(5),NQ(15),PARAMS(20,4),QTIME(15),
     2SSUMA(25,5),SUMA(25,5),MLC(15),NSET(10,550)
      COMMON  XISYS(4),TISYS(4),PRIOR(10),MTEAM(10),ZMEAN(10),REPAIR(10)
     1,MT(3),MTA(3),MSL,KOMP,MSL1,ATVL,OT,XIDLE(4),MISA(50),XMISA,
     2NORDER(50,3),MM(50,10),BUCKET(50,3),ONHAND,NBUCK,NET,DIF
     3,NFREZE(3),MTM(3),MTU(20,3),XMTU(12,3),YBAR(3),A(3),B(3)
     4,ISAMP,XTX,XTM,XWA(3),XWM(3),XWT(3),XDT(3),XDM(3),XDL(3),ZMT(4)
      REAL MT
      REAL MTM
C ADD ONE UNIT TO SYSTEM
      CALL TMSTAT(XISYS(4),TNOW,4)
      XISYS(4)=XISYS(4)+1
      M = ATTRIB(3)
      I = ATTRIB(4)
      KT = MTEAM(I)
      KP = PRIOR(I)
      CALL TMSTAT(XISYS(KT),TNOW,KT)
      XISYS(KT) = XISYS(KT) + 1.
C  DETERMINE THE NUMBER OF MISSILES ON ALERT
C  PUT COUNTER FOR MISSILE STATUS HERE
      XMISA = 0.0
      DO 1 J=1,MSL
      IF(MISA(J) .GT. 0)GO TO 1
      XMISA = XMISA + 1.
    1 CONTINUE
      CALL TMSTAT(XMISA,TNOW,8)
      XTT=TNOW-XTM
      XTM=XTM+XTT
      XTX=XTX+XMISA*XTT
C  DETERMINE IF THE RIGHT TYPE OF TEAM IS AVAILABLE
      BUFFER=0.0
      IF(MT(KT) .LT. MTA(KT))GO TO 6
C  A MAINTENANCE TEAM OF THE RIGHT TYPE IS NOT AVAILABLE SO DETERMINE IF THIS
C  FAILURE HAS PRIORITY.
C  SAVE ORIGINAL ATTRIBUTE VALUES
      IO = I
      MO = M
      KTO = KT
      KPO = KP
      IF(KP .NE. 1)GO TO 4
      XP=KT*10.+3.
      CALL FIND(XP,8,1,5,KCOL)
      IF(KCOL .NE. 0)GO TO 2
      XP=KT*10.+2.
      CALL FIND(XP,8,1,5,KCOL)
      IF(KCOL .EQ. 0)GO TO 4
    2 BUFFER = 1.0
      CALL REMOVE(KCOL,1)
C  PLACE THIS COMPONENT IN THE PROPER QUEUE FOR MISSILES DOWN AND WAITING
```

```
      M = ATTRIB(3)
      I = ATTRIB(4)
      XITIME=ATTRIB(6)
      KT = MTEAM(I)
      KP = PRIOR(I)
C  CAN THIS MISSILE BE PUT BACK ON ALERT WHILE WAITING
      IF(KP .LT. 3)GO TC 3
      MISA(M) = MISA(M) - 1
C  PLACE IN PROPER QUEUE
    3 ATTRIB(1) = KP
      ATTRIB(3)=M
      ATTRIB(4)=I
      ATTRIB(5) = KT
      ATTRIB(6)=XITIME
      ATTRIB(7) =TNOW
      ATTRIB(8)=1.
      CALL FILEM(KT+1)
C  THIS TEAM MUST NOW CLOSE UP THE LOW PRIORITY SITE AND REPAIR HIGHER PRIORITY
C SITE.
      I = IO
      M = MO
      KT = KTO
      KP = KPO
C  ADD CLOSING TIME OF LOW PRIORITY SITE TO OT.
      OT = OT + .5
      GO TO 10
C  THIS COMPONENT CANNOT BE REPAIRED NOW SO PLACE IT IN QUEUE(KT).
C  DETERMINE IF THIS COMPONENT WILL TAKE THE MISSILE OFF ALERT NOW
    4 IF(KP .EQ. 3)GO TC 5
C  UPDATE MISSILE STATUS
      MISA(M) = MISA(M) + 1
    5 ATTRIB(1)=KP
      ATTRIB(3)=M
      ATTRIB(4)=I
      ATTRIB(5) = KT
      ATTRIB(6) = TNOW
      ATTRIB(7) = TNOW
      ATTRIB(8)=1.
      CALL FILEM(KT+1)
      RETURN
C  THERE IS A MAINTENANCE TEAM AVAILABLE SO INCREASE THE NUMBER
C  OF MAINTENANCE TEAMS OF THIS TYPE IN USE BY ONE AND REPAIR COMPONENT
C  GATHER STATISTICS ON IDLE TIME
    6 IF(MT(KT) .LE. MTA(KT))GO TO 7
      XIDLE(KT)=0.0
      GO TO 9
    7 XMT = MT(KT)
      XMTA = MTA(KT)
      IF(MTA(KT) .GT. 0)GO TO 8
      XMTA = 1.0
    8 XIDLE(KT) = (XMTA - XMT)/XMTA
    9 CALL TMSTAT(XIDLE(KT),TNOW,KT+4)
      XDT(KT)=TNOW-XDM(KT)
      XDM(KT)=XDM(KT)+XDT(KT)
      XDL(KT)=XDL(KT)+XIDLE(KT)*XDT(KT)
```

```
C     COMPUTE THE AVERAGE NUMBER OF TEAMS USED
      MTM(KT)=MTM(KT)+MT(KT)*XDT(KT)
      MT(KT) = MT(KT) + 1
C     UPDATE MISSILE STATUS
   10 MISA(M) = MISA(M) + 1
      WT=0.
      CALL COLECT(WT,KT+4)
      XWM(KT)=XWM(KT)+WT
      XWT(KT)=XWT(KT)+1.0
C     DETERMINE SERVICE TIME AND PLACE IN FUTURE EVENTS FILE.
      ST = -REPAIR(I)*ALOG(RAN(0))+ATVL+OT
      MP=KT*10+KP
      ATTRIB(1)=TNOW+ST
      ATTRIB(2)=2.
      ATTRIB(3)=M
      ATTRIB(4)=I
      ATTRIB(5)=KT
      ATTRIB(6)=TNOW
      ATTRIB(7)=TNOW
      ATTRIB(8)=MP
      CALL FILEM(1)
      IF(BUFFER .EQ. 0.)GO TO 11
      OT=OT-.5
   11 RETURN
      END
```

```
      SUBROUTINE FIXED
      COMMON /LUNS/ LUCCR,LUPTR,LUPCH
      COMMON ID,IM,INIT,JEVENT,JMONIT,MFA,MSTOP,MX,MXC,NCOLCT,NHISTO,
     1NOQ,NORPT,NOT,NPRAMS,NRUN,NRUNS,NSTAT,OUT,SCALE,SEED,TNOW,
     2TSTART,TSTOP,MXX
      COMMON ATTRIB(8),ENQ(15),INN(15),JCELLS(5,22),KRANK(15),MAXNQ(15),
     1MFE(15),MLE(15),NCELLS(5),NQ(15),PARAMS(20,4),QTIME(15),
     2SSUMA(25,5),SUMA(25,5),MLC(15),NSET(10,550)
      COMMON  XISYS(4),TISYS(4),PRIOR(10),MTEAM(10),ZMEAN(10),REPAIR(10)
     1,MT(3),MTA(3),MSL,KOMP,MSL1,ATVL,OT,XIDLE(4),MISA(50),XMISA,
     2NORDER(50,3),MM(50,10),BUCKET(50,3),ONHAND,NBUCK,NET,DIF
     3,NFREZE(3),MTM(3),MTU(20,3),XMTU(12,3),YBAR(3),A(3),B(3)
     4,ISAMP,XTX,XTM,XWA(3),XWM(3),XWT(3),XDT(3),XDM(3),XDL(3),ZMT(4)
      REAL MT
      REAL MTM
      IMIS=ATTRIB(3)
      JCOMP=ATTRIB(4)
      KT=MTEAM(JCOMP)
      KP=PRIOR(JCOMP)
C  OBTAIN TIME IN SYSTEM STATISTICS
      CALL TMSTAT(XISYS(4),TNOW,4)
      XISYS(4)=XISYS(4)-1.
      CALL TMSTAT(XISYS(KT),TNOW,KT)
      XISYS(KT) = XISYS(KT) - 1.
      TISYS(KT) = TNOW - ATTRIB(6)
      TISYS(4) = TNOW - ATTRIB(6)
      CALL COLECT(TISYS(KT),KT)
      CALL COLECT(TISYS(4),4)
C  DETERMINE THE NUMBER OF MISSILES ON ALERT
      XMISA = 0.0
      DO 1 J=1,MSL
      IF(MISA(J) .GT. 0)GO TO 1
      XMISA = XMISA + 1.
    1 CONTINUE
      CALL TMSTAT(XMISA,TNOW,8)
      XTT=TNOW-XTM
      XTM=XTM+XTT
      XTX=XTX+XMISA*XTT
C  UPDATE MISSILE STATUS
      MISA(IMIS)=MISA(IMIS)-1
C  PUT THIS COMPONENT BACK ON ALERT
      ATTRIB(1)=TNOW-ZMEAN(JCOMP)*ALOG(RAN(0))
      ATTRIB(2)=1.
      ATTRIB(3)=IMIS
      ATTRIB(4)=JCOMP
      ATTRIB(5)=KT
      ATTRIB(8)=1.
      CALL FILEM(1)
      MM(IMIS,JCOMP)=TNOW
C DETERMINE IF THERE IS A WAITING LINE FOR THIS TEAM
      IF(NQ(KT+1))5,5,2
C  THERE ARE UNITS IN QUEUE(KT) SO REMOVE THE FIRST ONE WITH THE HIGHEST
C  PRIORITY AND REPAIR IT -- UPDATE STATISTICS.
    2 CONTINUE
      CALL REMOVE(MFE(KT+1),KT+1)
```

```
      IMIS=ATTRIB(3)
      JCOMP=ATTRIB(4)
      KT=ATTRIB(5)
      KP=PRIOR(JCOMP)
C  DETERMINE IF THIS COMPONENT WILL TAKE THE MISSILE OFF ALERT NOW
      IF(KP .LT. 3)GO TO 4
      XMISA = 0.0
C  DETERMINE THE NUMBER OF MISSILES ON ALERT
      DO 3 J = 1,MSL
      IF(MISA(J) .GT. 0)GO TO 3
      XMISA = XMISA + 1.
    3 CONTINUE
      CALL TMSTAT(XMISA,TNOW,8)
      XTT=TNOW-XTM
      XTM=XTM+XTT
      XTX=XTX+XMISA*XTT
C  UPDATE MISSILE STATUS
      MISA(IMIS)=MISA(IMIS)+1
    4 WT=TNOW-ATTRIB(7)
      CALL COLECT(WT,KT+4)
      XWM(KT)=XWM(KT)+WT
      XWT(KT)=XWT(KT)+1.0
      ST=-REPAIR(JCOMP)*ALOG(RAN(0))+ATVL+OT
      MP=KT*10+KP
      ATTRIB(1)=TNOW+ST
      ATTRIB(2)=2.
      ATTRIB(3)=IMIS
      ATTRIB(4)=JCOMP
      ATTRIB(5)=KT
      ATTRIB(8)=MP
      CALL FILEM(1)
      RETURN
C  THERE ARE NO COMPONENTS WAITING FOR THIS TEAM SO UPDATE STATISTICS.
    5 CONTINUE
C  GATHER STATISTICS ON IDLE TIME
      IF(MT(KT) .LE. MTA(KT))GO TO 6
      XIDLE(KT)=0.0
      GO TO 8
    6 XMT = MT(KT)
      XMTA = MTA(KT)
      IF(MTA(KT) .GT. 0)GO TO 7
      XMTA = 1.0
    7 XIDLE(KT) = (XMTA - XMT)/XMTA
    8 CALL TMSTAT(XIDLE(KT),TNOW,KT+4)
      XDT(KT)=TNOW-XDM(KT)
      XDM(KT)=XDM(KT)+XDT(KT)
      XDL(KT)=XDL(KT)+XIDLE(KT)*XDT(KT)
C  COMPUTE THE AVERAGE NUMBER OF TEAMS USED
      MTM(KT)=MTM(KT)+MT(KT)*XDT(KT)
      MT(KT) = MT(KT) - 1
      RETURN
      END
```

```
      SUBROUTINE FORCST
      COMMON /LUNS/ LUCDR,LUPTR,LUPCH
      COMMON ID,IM,INIT,JEVENT,JMONIT,MFA,MSTOP,MX,MXC,NCOLCT,NHISTO,
     1NOQ,NORPT,NOT,NPRAMS,NRUN,NRUNS,NSTAT,OUT,SCALE,SEED,TNOW,
     2TSTART,TSTOP,MXX
      COMMON ATTRIB(8),ENQ(15),INN(15),JCELLS(5,22),KRANK(15),MAXNQ(15),
     1MFE(15),MLE(15),NCELLS(5),NQ(15),PARAMS(20,4),QTIME(15),
     2SSUMA(25,5),SUMA(25,5),MLC(15),NSET(10,550)
      COMMON  XISYS(4),TISYS(4),PRIOR(10),MTEAM(10),ZMEAN(10),REPAIR(10)
     1,MT(3),MTA(3),MSL,KOMP,MSL1,ATVL,OT,XIDLE(4),MISA(50),XMISA,
     2NORDER(50,3),MM(50,10),BUCKET(50,3),ONHAND,NBUCK,NET,DIF
     3,NFREZE(3),MTM(3),MTU(20,3),XMTU(12,3),YBAR(3),A(3),B(3)
     4,ISAMP,XTX,XTM,XWA(3),XWM(3),XWT(3),XDT(3),XDM(3),XDL(3),ZMT(4)
      REAL MT
      REAL MTM
      NALYS=0
      KBUK=99
      DO 1 J=1,3
      MTM(J)=MTM(J)/XDM(J)
    1 CONTINUE
      MTM(1)=MTM(1)+MTM(1)*.25
      MTM(2)=MTM(2)+MTM(2)*.20
      MTM(3)=MTM(3)+MTM(3)*.05
      IF(TNOW .GT. 1345.)GO TO 3
      DO 2 J=1,3
      DO 2 I=1,16
      MTU(I,J)=MTM(J)
    2 CONTINUE
      GO TO 12
    3 CONTINUE
C   IDENTIFY ALTERNATIVE SAMPLES FOR BLOCKING
      IF(IBLOCK .EQ. 100)GO TO 4
      IBLOCK=100
      GO TO 5
    4 IBLOCK=200
    5 CONTINUE
      ICOUNT=ICOUNT+1
      ISAMP=ICOUNT+IBLOCK
      XTX=XTX/XTM
      IEXP=4
      IRUN=52
      DO 6 I=1,3
      ZMT(I)=MTA(I)
      CALL TMSTAT(ZMT(I),TNOW,I+8)
      XDL(I)=XDL(I)/XDM(I)
      XWA(I)=XWM(I)/XWT(I)
    6 CONTINUE
      ZMT(4)=MTA(1)+MTA(2)+MTA(3)
      CALL TMSTAT(ZMT(4),TNOW,12)
      PRINT 803,IEXP,IRUN,ISAMP,XTX,(XDL(J),J=1,3),(XWA(J),J=1,3)
     1,(ZMT(J),J=1,4),NALYS
  803 FORMAT(2X,I1,2X,I2,2X,I3,1X,F6.2,3F6.3,3F7.2,4F7.2,2X,I1)
      IF(TNOW .LE. 9745)GO TO 8
      BLOCK=BLOCK+1.0
      IF(BLOCK .GT. 1.0)GO TO 7
```

```
      ISAMP=0
      ICOUNT=1
      IBLOCK=100
      ISAMP=ICOUNT+IBLOCK
    7 CONTINUE
      WRITE(30,99)IEXP,IRUN,ISAMP,XTX,(XML(J),J=1,3),(XWA(J),J=1,3)
     1,(ZMT(J),J=1,4),NALYS
   99 FORMAT(I1,I2,I3,F6.2,3F6.3,7F7.2,I1)
    8 CONTINUE
C  ALLOW TEAM USAGE TO STABILIZE
C  CHANGE THE NUMBER OF TEAMS ASSIGNED BY ORDER(I,1)
      DO 10 I=1,3
      MTA(I)=MTA(I)+NORDER(1,I)
      IF(MTA(I) .GE. MT(I))GO TO 9
      MTA(I)=MT(I)
    9 IF(MTA(I) .GE. 1)GO TO 10
      MTA(I) = 1
   10 CONTINUE
C  MOVE FROZEN PERIOD  FORWARD BY ONE WEEK
C  FOR TEAM 1 NFREZE = 30 WEEKS (BUCKETS) OR 5040 HOURS
C  FOR TEAM 2 NFREZE = 20 WEEKS (BUCKETS) OR 3360 HOURS
C  FOR TEAM 3 NFREZE = 10 WEEKS (BUCKETS) OR 1680 HOURS
      DO 11 J=1,3
      K=NFREZE(J)
      DO 11 I=1,K
      NORDER(I,J)=NORDER(I+1,J)
C  ZERO OUT MASTER SCHEDULE (BUCKET(I,J)) FOR NEW COMPUTATIONS
      BUCKET(I,J)=0.0
   11 CONTINUE
C  DETERMINE THE MASTER SCHEDULE -- REQUIREMENTS FOR MAN HOURS
   12 DO 23 I=1,MSL
      DO 22 J=1,KOMP
C  MOD I (KBUK) COMES AT 30 WEEKS
C  MOD II (LBUK) COMES AT 35 WEEKS
      LBUK=(15624.-TNOW)/168.
      KBUK=(14784.-TNOW)/168.
      IF(TNOW .GT. 1345)GO TO 13
      MM(I,J)=0.0
   13 NTIME=NFAIL=TNOW
      NFAIL=NFAIL+(TNOW-MM(I,J))+ZMEAN(J)+1
      IF(TNOW .GT. 14780.)GO TO 14
      MTEAM(9)=2
      ZMEAN(9)=780.
      REPAIR(9)=26.
   14 IF(TNOW .GT. 15620.)GO TO 15
      MTEAM(7)=2
      ZMEAN(7)=800.
      REPAIR(7)=18.
   15 K=0
   16 NTIME=NTIME+NBUCK
      K=K+1
      IF(K .EQ. KBUK)GO TO 17
      GO TO 18
   17 MTEAM(9)=1
      ZMEAN(9)=428.
```

```
      REPAIR(9)=31.2
   18 IF(K .EQ. LBUK)GO TO 19
      GO TO 20
   19 MTEAM(7)=1
      ZMEAN(7)=200.
      REPAIR(7)=25.2
   20 NT=MTEAM(J)
      IK=NFREZE(NT)+1
      IF(K .GT. IK)GO TO 38
   21 IF(NFAIL .GE. NTIME)GO TO 16
      BUCKET(K,MTEAM(J))=BUCKET(K,MTEAM(J))+REPAIR(J)/168.
      NFAIL=NFAIL+ZMEAN(J)
      NT=MTEAM(J)
      NF=TNOW+IK+NBUCK
      IF(NFAIL .LT. NF)GO TO 21
   22 CONTINUE
   23 CONTINUE
      IF(TNOW .GT. 1345.)GO TO 27
C  INITIALIZE GROSS TO NET
      BLOCK=0.0
      ISAMP=0
      ICOUNT=0
      IBLOCK=200
      PRINT 802
  802 FORMAT(4X,*SAMPLE*,4X,*ALERT*,5X,*IDLE 1,2,3*,9X,*WAITING TIME*,
     16X,*NO. OF TEAMS 1,2,3,TOTAL*)
      DO 26 J=1,3
      K=NFREZE(J)
      NORD2=BUCKET(1,J)
      IF(BUCKET(1,J) .EQ. NORD2)GO TO 24
      NORD2=NORD2+1
   24 NORDER(1,J)=NORD2-MTM(J)
      DO 26 I=1,K
      NORD1=NORD2
      NORD2=BUCKET(I+1,J)
      IF(BUCKET(I+1,J) .EQ. NORD2)GO TO 25
      NORD2=NORD2+1
   25 NORDER(I+1,J)=NORD1-NORD2
   26 CONTINUE
C  PERFORM GROSS-TO-NET CALCULATIONS
   27 DO 37 J=1,3
      XFIRE=0.0
      IF(J .LT. 3)GO TO 28
      IFIRE=10
      XDIV=3.
      GO TO 30
   28 IF(J .LT. 2)GO TO 29
      IFIRE=10
      XDIV=3.
      GO TO 30
   29 IFIRE=10
      XDIV=3.
   30 CONTINUE
      K=NFREZE(J)-1
      XKT=NQ(J+1)*34./168.
```

```
      ONHAND=MTA(J)-MTM(J)-XKT
      MTM(J)=0
      DIF=BUCKET(1,J)-ONHAND-NORDER(1,J)
      DO 35 I=1,K
      IF(I .LT. 8)GO TO 34
      IF(I .GT. IFIRE)GO TO 34
      XFIRE=XFIRE+DIF
      IF(I .NE. IFIRE)GO TO 34
      XFIRE=XFIRE/XDIV
      IF(XFIRE .GE. 0)GO TO 34
      IF(J .LT. 3)GO TO 31
      SAFETY=XFIRE*(-.05)
      GO TO 33
   31 IF(J .LT. 2)GO TO 32
      SAFETY=XFIRE*(-.20)
      GO TO 33
   32 SAFETY=XFIRE*(-.25)
   33 CONTINUE
      NORD=XFIRE+SAFETY
      NORDER(9,J)=NORD
      DIF=DIF-XFIRE+SAFETY
   34 DIF=DIF+(BUCKET(I+1,J)-BUCKET(I,J))-NORDER(I+1,J)
   35 CONTINUE
      NORD=DIF
      IF(DIF .EQ. NORD)GO TO 36
      IF(DIF .LE. 0.)GO TO 36
      NORD=NORD+1
   36 NORDER(I+1,J)=NORD
   37 CONTINUE
  PROGRAM NEXT FORECAST
      VALUE=TNOW+NBUCK
      ATTRIB(1)=VALUE
      ATTRIB(2)=3.
      ATTRIB(3)=0.
      ATTRIB(4)=0.
      ATTRIB(5)=0.
      ATTRIB(8)=1.
      CALL FILEM(1)
  THE FOLLOWING STATEMENTS RETURN ORIGINAL VALUES TO MODIFIED VAR.
      IF(TNOW .GT. 14784.)GO TO 38
      MTEAM(9)=2
      ZMEAN(9)=780.
      REPAIR(9)=26.
   38 IF(TNOW .GT. 15624.)GO TO 39
      MTEAM(7)=2
      ZMEAN(7)=800.
      REPAIR(7)=18.
   39 XDM(1)=XDM(2)=XDM(3)=0.01
      XWM(1)=XWM(2)=XWM(3)=0.0
      XWT(1)=XWT(2)=XWT(3)=0.01
      XWA(1)=XWA(2)=XWA(3)=XTX=XTM=0.0
      XDL(1)=XDL(2)=XDL(3)=0.0
      ZMT(1)=ZMT(2)=ZMT(3)=ZMT(4)=0.0
      RETURN
      END
```

```
      SUBROUTINE LOAD
      COMMON /LUNS/ LUCDR,LUPTR,LUPCH
      COMMON ID,IM,INIT,JEVENT,JMONIT,MFA,MSTOP,MX,MXC,NCOLCT,NHISTO,
     1NOQ,NORPT,NOT,NPRAMS,NRUN,NRUNS,NSTAT,OUT,SCALE,SEED,TNOW,
     2TSTART,TSTOP,MXX
      COMMON ATTRIB(8),ENQ(15),INN(15),JCELLS(5,22),KRANK(15),MAXNQ(15),
     1MFE(15),MLE(15),NCELLS(5),NQ(15),PARAMS(20,4),QTIME(15),
     2SSUMA(25,5),SUMA(25,5),MLC(15),NSET(10,550)
      COMMON  XISYS(4),TISYS(4),PRIOR(10),MTEAM(10),ZMEAN(10),REPAIR(10)
     1,MT(3),MTA(3),MSL,KOMP,MSL1,ATVL,OT,XIDLE(4),MISA(50),XMISA,
     2NORDER(50,3),MM(50,10),BUCKET(50,3),ONHAND,NBUCK,NET,DIF
     3,NFREZE(3),MTM(3),MTU(20,3),XMTU(12,3),YBAR(3),A(3),B(3)
     4,ISAMP,XTX,XTM,XWA(3),XWM(3),XWT(3),XDT(2),XDM(3),XDL(3),ZMT(4)
      PRINT 190
  190 FORMAT(2X,*LOAD OR MOD OCCURRING NOW*)
      IF(TNOW .GT. 1.)GO TO 7
      PRINT 191
  191 FORMAT(2X,*INITIAL LOAD OCCURRING NOW*)
      DO 6 IMIS=1,MSL
      MISA(IMIS)=0
      DO 5 JCOMP=1,KOMP
      VALUE=-ZMEAN(JCOMP)*ALOG(RAN(0))
      ATTRIB(1)=VALUE
      ATTRIB(2)=1.
      ATTRIB(3)=IMIS
      ATTRIB(4)=JCOMP
      ATTRIB(5)=MTEAM(JCOMP)
      ATTRIB(8)=1.
      CALL FILEM(1)
    5 CONTINUE
    6 CONTINUE
C PROGRAM TIME OF NEXT MODIFICATION:THIS IS REDUNDANT FOR MRP
C SO THE FOLLOWING STATEMENTS WILL BE BYPASSED.
C           INITIALIZATION = 1344
C           START-UP       = 8400
C           RUN FOR 30 WKS = 5040
C     TOTAL TIME UNTIL MOD=14784
      GO TO 8
      VALUE=TNOW+14784
      ATTRIB(1)=VALUE
      ATTRIB(2)=4.
      ATTRIB(3)=0.
      ATTRIB(4)=0.
      ATTRIB(5)=0.
      ATTRIB(8)=1.
      CALL FILEM(1)
      GO TO 8
    7 CONTINUE
C IMPLEMENT SIMULTANEOUS MODIFICATIONS
      ZMEAN(9)=ZMEAN(9)*.60
      REPAIR(9)=REPAIR(9)*1.40
      MTEAM(9)=1
    8 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE ENDSIM
      COMMON /LUNS/ LUCDR,LUPTR,LUPCH
      COMMON ID,IM,INIT,JEVENT,JMONIT,MFA,MSTOP,MX,MXC,NCOLCT,NHISTO,
     1NOQ,NORPT,NOT,NPRAMS,NRUN,NRUNS,NSTAT,OUT,SCALE,SEED,TNOW,
     2TSTART,TSTOP,MXX
      COMMON ATTRIB(8),ENQ(15),INN(15),JCELLS(5,22),KRANK(15),MAXNQ(15),
     1MFE(15),MLE(15),NCELLS(5),NQ(15),PARAMS(20,4),QTIME(15),
     2SSUMA(25,5),SUMA(25,5),MLC(15),NSET(10,550)
      COMMON  XISYS(4),TISYS(4),PRIOR(10),MTEAM(10),ZMEAN(10),REPAIR(10)
     1,MT(3),MTA(3),MSL,KOMP,MSL1,ATVL,OT,XIDLE(4),MISA(50),XMISA,
     2NORDER(50,3),MM(50,10),BUCKET(50,3),ONHAND,NBUCK,NET,DIF
     3,NFREZE(3),MTM(3),MTU(20,3),XMTU(12,3),YBAR(3),A(3),B(3)
     4,ISAMP,XTX,XTM,XWA(3),XWM(3),XWT(3),XDT(3),XDM(3),XDL(3),ZMT(4)
      CALL TMSTAT(XISYS(1),TNOW,1)
      CALL TMSTAT(XISYS(2),TNOW,2)
      CALL TMSTAT(XISYS(3),TNOW,3)
      CALL TMSTAT(XISYS(4),TNOW,4)
      CALL TMSTAT(XIDLE(1),TNOW,5)
      CALL TMSTAT(XIDLE(2),TNOW,6)
      CALL TMSTAT(XIDLE(3),TNOW,7)
      CALL TMSTAT(XMISA,TNOW,8)
      ZMT(1)=MTA(1)
      CALL TMSTAT(ZMT(1),TNOW,9)

      ZMT(2)=MTA(2)
      CALL TMSTAT(ZMT(2),TNOW,10)
      ZMT(3)=MTA(3)
      CALL TMSTAT(ZMT(3),TNOW,11)
      ZMT(4)=MTA(1)+MTA(2)+MTA(3)
      CALL TMSTAT(ZMT(4),TNOW,12)
C   PULL FINAL STATISTICS OUT OF GASP
      MSTOP=-1
      RETURN
      END
```

```
000111111111122222222223333333333444444444455555555556666666666777777777778
5789012345678901234567890123456789012345678901234567890123456789012345678901234567890

    GASP22           1   MRP/MANPOWER SIMULATION -- DISSERTATION
 0     7    12   550     8     4     0
 0     0     0           0           0 123456789
 1     1     1
 1     1     1

 1       0           4
 1    1344           3
 1   27217           5
 0
```

```
********************************************************************************

DAWSAES    DROP B
SEQ        BIN 88

                                 DDDDDDD      AA      WW     WW   SSSSSS      AA
                                 DD    DD    AAAA     WW     WW  SS    SS    AAAA
                                 DD    DD   AA  AA    WW     WW  SS         AA  AA
                                 DD    DD  AA    AA   WW     WW   SSSSSS   AA    AA
                                 DD    DD  AA    AA   WW WW WW         SS  AA    AA
                                 DD    DD  AAAAAAAA   WWWWWWWW         SS  AAAAAAAA
                                 DD    DD  AA    AA   WWW  WWW         SS  AA    AA
                                 DD    DD  AA    AA   WW     WW  SS    SS  AA    AA
                                 DDDDDDD   AA    AA   W       W   SSSSSS   AA    AA

                                   ********************************************
                                   ********************************************

DAWSAES. 76/05/18. INDIANA UNIVERSITY - LEVEL 9.

09.22.24.JOB READ AT  09.22.22. 76/05/18.
09.22.24.DAW,T430,DRU.
09.22.24.ACCOUNT,7016,.
09.22.24.PAGES=100.
09.22.24.CARDS=110.
09.22.24.GET(TMP5)
09.22.25.GET(TAPE60=COM3)
09.22.25.ROUTE(OUTPUT,WASTE,EJ,L=WCC)
09.22.26.GET(TAPE5=GASPBIN)
09.22.28.FTN(R=0,I=TMP5)
09.23.42.     5.282 CP SECONDS COMPILATION TIME
09.23.42.LOAD(TAPE5)
09.23.43.LGO.
10.51.12.STOP
10.51.12.REWIND,TAPE30.
10.51.12.COPYSBF(TAPE30,OUTPUT)
10.51.12. COPY COMPLETE.
10.51.13.CP      4028    SEC.
10.51.13.CP      257.111 SEC.
10.51.13.CM        1.444 KWH.
10.51.13.MS        4.186 KPR.
10.51.13.CM        5.200 MWS.
10.51.13.BU        5.827

 76/05/18. 10.51.15.

********************************************************************************
```

```
      SUBROUTINE FORCST
      COMMON /LUNS/ LUCDR,LUPTR,LUPCH
      COMMON ID,IM,INIT,JEVENT,JMONIT,MFA,MSTOP,MX,MXC,NCOLCT,NHISTO,
     1NOQ,NORPT,NOT,NPRAMS,NRUN,NPUNS,NSTAT,OUT,SCALE,SEED,TNOW,
     2TSTART,TSTOP,MXX
      COMMON ATTRIB(8),ENQ(15),INN(15),JCELLS(5,22),KRANK(15),MAXNQ(15),
     1MFE(15),MLE(15),NCELLS(5),NQ(15),PARAMS(20,4),QTIME(15),
     2SSUMA(25,5),SUMA(25,5),MLC(15),NSET(10,550)
      COMMON  XISYS(4),TISYS(4),PRIOR(10),MTEAM(10),ZMEAN(10),REPAIR(10)
     1,MT(3),MTA(3),MSL,KOMP,MSLI,ATVL,OT,XIDLE(4),MISA(50),XMISA,
     2NORDER(50,3),MM(50,10),BUCKET(50,3),ONHAND,NBUCK,NET,DIF
     3,NFREZE(3),MTM(3),MTU(20,3),XMTU(12,3),YBAR(3),A(3),B(3)
     4,ISAMP,XTX,XTM,XWA(3),XWM(3),XWT(3),XDT(3),XDM(3),XDL(3),ZMT(4)
      REAL MT
      REAL MTM
      NALYS=4
      XBAR=6.5
      DO 1 J=1,3
      MTM(J)=MTM(J)/XDM(J)
    1 CONTINUE
      MTM(1)=MTM(1)+MTM(1)*.25
      MTM(2)=MTM(2)+MTM(2)*.20
      MTM(3)=MTM(3)+MTM(3)*.05
      IF(TNOW .GT. 1345.)GO TO 3
      DO 2 J=1,3
      DO 2 I=1,16
      MTU(I,J)=MTM(J)
    2 CONTINUE
      GO TO 11
    3 CONTINUE
C   IDENTIFY ALTERNATIVE SAMPLES FOR BLOCKING
      IF(IBLOCK .EQ. 100)GO TO 4
      IBLOCK=100
      GO TO 5
    4 IBLOCK=200
    5 CONTINUE
      ICOUNT=ICOUNT+1
      ISAMP=ICOUNT+IBLOCK
      XTX=XTX/XTM
      IEXP=4
      IRUN=62
      DO 6 I=1,3
      ZMT(I)=MTA(I)
      CALL TMSTAT(ZMT(I),TNOW,I+8)
      XDL(I)=XDL(I)/XDM(I)
      XWA(I)=XWM(I)/XWT(I)
    6 CONTINUE
      ZMT(4)=MTA(1)+MTA(2)+MTA(3)
      CALL TMSTAT(ZMT(4),TNOW,12)
      PRINT 803,IEXP,IRUN,ISAMP,XTX,(XDL(J),J=1,3),(XWA(J),J=1,3)
     1,(ZMT(J),J=1,4),NALYS
  803 FORMAT(2X,I1,2X,I2,2X,I3,1X,F6.2,3F6.3,3F7.2,4F7.2,2X,I1)
      IF(TNOW .LE. 9745)GO TO 8
      BLOCK=BLOCK+1.0
      IF(BLOCK .GT. 1.0)GO TO 7
```

```
      ISAMP=0
      ICOUNT=1
      IBLOCK=100
      ISAMP=ICOUNT+IBLOCK
    7 CONTINUE
      WRITE(30,99)IEXP,IRUN,ISAMP,XTX,(XDL(J),J=1,3),(XWA(J),J=1,3)
     1,(ZMT(J),J=1,4),NALYS
   99 FORMAT(I1,I2,I3,F6.2,3F6.3,7F7.2,I1)
    8 CONTINUE
C   ALLOW TEAM USAGE TO STABILIZE
C   CHANGE THE NUMBER OF TEAMS ASSIGNED BY ORDER(I,1)
      DO 9 I=1,3
      MTA(I)=MTA(I)+NORDER(1,I)
      IF(MTA(I) .GE. 1)GO TO 9
      MTA(I)=1
    9 CONTINUE
C   MOVE FROZEN PERIOD FORWARD BY ONE WEEK
C   FOR TEAM 1 NFREZE = 30 WEEKS (BUCKETS) OR 5040 HOURS
C   FOR TEAM 2 NFREZE = 20 WEEKS (BUCKETS) OR 3360 HOURS
C   FOR TEAM 3 NFREZE = 10 WEEKS (BUCKETS) OR 1680 HOURS
      DO 10 J=1,3
      K=NFREZE(J)
      DO 10 I=1,K
      NORDER(I,J)=NORDER(I+1,J)
C   ZERO OUT PROJECTED REQUIREMENT (BUCKET(I,J)) FOR NEW COMPUTATIONS
      BUCKET(I,J)=0.0
   10 CONTINUE
C   DETERMINE REQUIREMENTS BY TEAM
C   UPDATE MAINTENANCE TEAM MAXIMUM UTILIZATION
   11 DO 13 J=1,3
      DO 12 I=1,15
      MTU(I,J)=MTU(I+1,J)
   12 CONTINUE
      MTU(16,J)=MTM(J)
   13 CONTINUE
C   THE FOLLOWING ELIMINATES THE WEIGHTED AVERAGE
      DO 15 J=1,3
      YBAR(J)=0.0
      DO 14 I=1,12
      XMTU(I,J)=MTU(I+4,J)
      YBAR(J)=YBAR(J)+XMTU(I,J)
   14 CONTINUE
      YBAR(J)=YBAR(J)/12.
   15 CONTINUE
C   DETERMINE REGRESSION COEFFICIENTS
      DO 17 J=1,3
      SUM=0.0
      SUMXSQ=0.0
      DO 16 I=1,12
      XI=I
      X=XI-XBAR
      Y=XMTU(I,J)-YBAR(J)
      SUM=SUM+X*Y
      SUMXSQ=SUMXSQ+X**2
   16 CONTINUE
```

```
      B(J)=SUM/SUMXSQ
      A(J)=YBAR(J)-B(J)*XBAR
   17 CONTINUE
C  MAKE TMP PROJECTIONS
      DO 23 J=1,3
      IF(TNOW .GT. 15629.)GO TO 20
      XMOD3=0.0
      LBUK=0
      KBUK=0
      IF(J .EQ. 3)GO TO 20
C  THIS ROUTINE PREPARES TMP FOR SIMULTANEOUS MODS:TEAM CHAMGE.
      XT=4.
      IF(TNOW .LT. 14789.)GO TO 18
      XT=3.
   18 XMOD3=MTM(2)/XT
      IF(J .EQ. 1)GO TO 19
      XMOD3=-XMOD3
   19 KBUK=(14784.-TNOW)/168.
      LBUK=(15624.-TNOW)/168.
C  XMOD3 IS THE NUMBER OF TEAM HOURS TO BE TRANSFERRED FROM
C  TEAM 2 TO TEAM 1.
C  KBUK IS THE BUCKET IN WHICH SIMULTANEOUS MOD I WILL TAKE PLACE
C  LBUK IS THE BUCKET IN WHICH SIMULTANEOUS MOD II WILL TAKE PLACE
   20 K=NFREZE(J)
      DO 22 I=1,K
      XK=K
      BUCKET(I,J)=A(J)+B(J)*XK
      IF(J .EQ. 3)GO TO 22
      IF(LBUK .EQ. I)GO TO 21
      IF(KBUK .NE. I)GO TO 22
   21 BUCKET(I,J)=BUCKET(I,J)+XMOD3
   22 CONTINUE
   23 CONTINUE
      IF(TNOW .GT. 1345.)GO TO 27
C  INITIALIZE GROSS TO NET
      BLOCK=0.0
      ISAMP=0
      ICOUNT=0
      IBLOCK=200
      PRINT 802
  802 FORMAT(4X,*SAMPLE*,4X,*ALERT*,5X,*IDLE 1,2,3*,9X,*WAITING TIME*,
     16X,*NO. OF TEAMS 1,2,3,TOTAL*)
      DO 26 J=1,3
      K=NFREZE(J)
      NORD2=BUCKET(1,J)
      IF(BUCKET(1,J) .EQ. NORD2)GO TO 24
      NORD2=NORD2+1
   24 NORDER(1,J)=NORD2-MTM(J)
      DO 26 I=1,K
      NORD1=NORD2
      NORD2=BUCKET(I+1,J)
      IF(BUCKET(I+1,J) .EQ. NORD2)GO TO 25
      NORD2=NORD2+1
   25 NORDER(I+1,J)=NORD1-NORD2
   26 CONTINUE
```

AD-A046 071 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OHIO F/G 5/9
MANPOWER PLANNING THROUGH MATERIAL REQUIREMENTS PLANNING (MRP):--ETC(U)
1976 D A WILKERSON
UNCLASSIFIED AFIT-CI-77-63 NL

2 OF 2
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```
C  PERFORM GROSS-TO-NET CALCULATIONS
   27 DO 37 J=1,3
      XFIRE=0.0
      IF(J .LT. 3)GO TO 28
      IFIRE=10
      XDIV=3.
      GO TO 30
   28 IF(J .LT. 2)GO TO 29
      IFIRE=10
      XDIV=3.
      GO TO 30
   29 IFIRE=10
      XDIV=3.
   30 CONTINUE
      K=NFREZE(J)-1
C  XKT CONSIDERS THE NUMBER OF TEAMS REQUIRED TO ELIMINATE THE
C  BACKLOG IN WEEK.
      XKT=NQ(J+1)*34./168.
      ONHAND=MTA(J)-MTM(J)-XKT
      MTM(J)=0
      DIF=BUCKET(1,J)-ONHAND-NORDER(1,J)
      DO 35 I=1,K
      IF(I .LT. 8)GO TO 34
      IF(I .GT. IFIRE)GO TO 34
      XFIRE=XFIRE+DIF
      IF(I .NE. IFIRE)GO TO 34
      XFIRE=XFIRE/XDIV
      IF(XFIRE .GE. 0)GO TO 34
      IF(J .LT. 3)GO TO 31
      SAFETY=XFIRE*(-.05)
      GO TO 33
   31 IF(J .LT. 2)GO TO 32
      SAFETY=XFIRE*(-.20)
      GO TO 33
   32 SAFETY=XFIRE*(-.25)
   33 CONTINUE
      NORD=XFIRE+SAFETY
      NORDER(9,J)=NORD
      DIF=DIF-XFIRE+SAFETY
   34 DIF=DIF+(BUCKET(I+1,J)-BUCKET(I,J))-NORDER(I+1,J)
   35 CONTINUE
      NORD=DIF
      IF(DIF .EQ. NORD)GO TO 36
      IF(DIF .LE. 0.)GO TO 36
      NORD=NORD+1
   36 NORDER(I+1,J)=NORD
   37 CONTINUE
C  PROGRAM NEXT FORECAST
      VALUE=TNOW+NBUCK
      ATTRIB(1)=VALUE
      ATTRIB(2)=3.
      ATTRIB(3) = 0.
      ATTRIB(4) = 0.
      ATTRIB(5) = 0.
      ATTRIB(8)=1.
```

APPENDIX C

PROGRAM VARIABLES

List of Program Variables

VARIABLE	DESCRIPTION
ATVL	Average travel time; used in MRP master schedule computations.
BUCK(I)	Time bucket or period; measured from TIME.
BUCKET(I,L)	The number of teams of type L required in time bucket I. Used in master schedule explosions.
BUFFER	Used to allow manipulation of data without loss of original data.
DIF(J)	The difference between manpower loading and projected need for team J.
ELAPSE	The interval since the last failure or repair occurred.
END	Time of the end of the simulation run.
FAIL(J,K)	A temporary variable used to establish the time at which component K of missile J will fail next.
HORIZON	The last time bucket or time period considered for manpower planning forecasts.
IONHAND	The number of maintenance teams on hand; used for gross-to-net continuous calculations for MRP.
MM(I,L)	Master matrix; maintains the time at which component L on missile I failed last for MRP calculations.
MSL	Number of missiles in the system.
MT(I)	The number of maintenance teams of type I in use.
MTA(I)	The number of maintenance teams of type I assigned.
MTEAM(I)	The teams which are designated to repair component I.
MTM(I)	The average number of maintenance teams of type I assigned.
MTU(I,L)	Historical data used for TMP calculations; the number of maintenance hours used by team type L in period I.
NBUCK	Time period or bucket; one week or 168 hours.
NFAIL	The next time that the component being considered is expected to fail; used in MRP master schedule calculations.
NFREEZE	Frozen period - beyond which teams may be added or dropped For adding additional teams: Team 1 30 weeks Team 2 20 weeks Team 3 10 weeks For eliminating teams: All teams 8 weeks

NHORIZON	Horizon; the end of the last time bucket considered in forecast calculations.
NTIME	Time bucket being considered during MRP master schedule computations.
ORDER(I,J)	Number of teams to be added or dropped; Team J for period I; these orders are firm if the frozen period has passed.
OT	Time required to open a missile silo.
PM	Preventive maintenance decision point.
PRIOR(I)	Maintenance priority for component I.
REPAIR(I)	Mean time required to repair component I.
SAFETY	Safety stock added for TMP projections.
ST	Service time; calculated by using REPAIR(I) for component being considered and transposing that into an exponential distribution.
TIME	Current simulation clock time.
TVL	Temporary variable used to identify the travel time to the missile being considered.
VALUE	Temporary variable used to identify values to be placed in order by the NSET array (it may be service time, repair time, or priority).
XFIRE	The number of teams to be fired in period 8.
XMOD(I)	Impending modification number I to the missile system configuration.
ZMEAN(I)	Mean time before failure for component I.

APPENDIX D

COMPONENT PARAMETERS

	MISSILE COMPONENT	MTBF	PRIORITY*	MAINTENANCE TEAM REQ'D	MEAN REPAIR TIME
1	Reentry Vehicle	400 hours	1	1	74 hours
2	Security System	220	1	3	22
3	Environmental Control System	160	1	2	12
4	Guidance & Control System	280	2	1	68
5	Autocollimator	1,800	2	1	10
6	Digital Relay System	1,200	2	3	8
7	Turbogenerator	800	3	2	18
8	Communications System	180	3	3	13
9	Firing Squibs	780	3	2	26
10	Umbilical & Nozzel Control	240	3	2	9

Priority

1 Critical Failure - Preempts all others

2 Major Failure - Will preempt priority 3 unless maintenance team is already at priority 3 site

3 Minor failure or preventive maintenance

---

*Missiles will not be taken off alert by priority 3 failure until that component is being repaired.

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