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A MODEL FOR PREDICTING INTEGRATED MAN-MACHINE SYSTEMS RELIABILITY

prepared for

Naval Sea Systems Command
Department of the Navy
Washington, D. C.

Applied Psychological Services
Science Center
Wayne, Pa.

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The degree of success in producing rational output achieved during a set of basic runs using the revised model and program is discussed.

A MODEL FOR PREDICTING INTEGRATED MAN-MACHINE SYSTEM RELIABILITY

Model Logic and Description

Arthur I. Siegel
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J. Jay Wolf
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CHAPTER I

INTRODUCTION AND BACKGROUND

General Overview

The integration of human reliability (HR) and equipment reliability (ER) data into a single comprehensive model for predicting system reliability (SR) has been one of the major expressed concerns of Navy system planners (Blanchard, 1972). Efforts to use currently available models, however, have not met with desired success levels. An attempt was made, for example, to include human performance data in the WSEIAC (1965) model, even though an explicit basis was not originally provided in the model for such consideration. As noted by Blanchard (1972) "... attempting to force human performance characteristics relative to a particular system design into an available structure provided by a model developed to account for equipment consideration is extremely difficult and grossly inadequate." Similarly, efforts to incorporate human performance data into the GEM (Orbach, 1968) and RAMA (Hamilton & Bennett, 1970) models have not as yet proved useful. Moreover, even when separately noted, the contributions of HR and ER to SR have not been quantified in an easily generalizable fashion. The result makes extrapolations to new environments/equipments/personnel difficult (Smith et al., 1970). This problem is primarily a result of the absence of a clear and concise statement defining the separate characteristics and properties relevant both to ER determination and HR determination and the development of a unifying strategy for incorporating them into an SR framework. While a number of equipment reliability models are currently available (e.g., MIL-STD-756), there has only been limited work in human reliability modeling (Siegel & Federman, 1974, Federman & Siegel, 1973).

Prior NAVSHIPS Sponsored Efforts

Over the past several years, Applied Psychological Services has been engaged in developing, testing, and demonstrating a family of man-machine computer simulation models. Considerable emphasis has been given in these models to the HR aspects. The earliest model has also been successful in showing the utility of the stochastic simulation approach for predicting human reliability in the electronic equipment maintenance context (Siegel & Federman, 1974). The results of this prior work point out and support the feasibility of the general approach for HR prediction purposes. On the basis of this prior effort it seemed that a similar approach to the prediction of HR in all contexts (electrical, electromechanical, mechanical, and electronic maintenance, as well as equipment operation) offered considerable promise.

However, the stochastic simulation model employed previously for HR prediction is limited to simulation of tasks performed by one or two operators and is further limited because it is not easily adaptable for total system simulation purposes. Accordingly, a model was sought which would allow simulation of the actions and behaviors of larger groups of men and total equipment systems. A further prerequisite in such a model is the ability to accept and interact with ER data so as to yield an integrated SR numeric. Quite obviously, the output should be analyzable into the contributors to high or low SR.

A second Applied Psychological Services' large crew model was also considered. This model simulated psychosocial and performance interactions for groups of operators selected from crews of up to 90 men. Predictions made by the model, mostly based on HR considerations, include system effectiveness, crew morale and cohesiveness, operator orientation, sickness, and proficiency. In this model, each day of a multiday mission is simulated to yield crew-mission evaluation.

However, work with this model indicated that it was not appropriate for intermediate size crews, because as crew size decreases, so does group size, mitigating the applicability of model logic based on HR group theoretic concepts.

Another model developed and validated at Applied Psychological Services under Office of Naval Research sponsorship was considered. This model, called the intermediate size model (ISM), has been fully described elsewhere (Siegel, Lautman, & Wolf, 1972; Siegel, Wolf, & Cosentino, 1971; Siegel, Wolf, & Fischl, 1969). Examples of variables included in the model are: crewman proficiency, crew morale, level of aspiration, fatigue, and stress.

The ISM simulates the acts and behaviors of individuals and/or groups of persons as they perform the tasks required for the operation of a man-machine system. While the model can also simulate tasks performed by a smaller number of persons, its primary advantage is its ability to simulate teams of 4 to 20 mean. As such, it complements the one man - two man model (Siegel & Wolf, 1962; 1969) and the large size crew models which had been previously developed and validated at Applied Psychological Services.

As in the large crew model, the approach to the problem of crew simulation in the ISM is through the formulation of a representation which simulates group activity and which yields operational (workload) measures, as well as measures of man-machine system performance efficiency. Because the model is to be used in simulating difficult and untried missions, in which the operators' physical and mental limitations may plan an important part, original emphasis in ISM development was placed on human or operator-oriented variables. Nevertheless, the more ordinary operational variables (the amount of time worked by operators, status of supplies, etc.) are also included. It has been found helpful to consider the separation of the principal model variables into these two categories: psychological or operator oriented variables, and operational variables. Examples of psychological variables are competence, characteristic work pace, physical capability, aspiration level, stress tolerance, and state of fatigue of the operator. Examples of operational variables simulated are level of consumables, performance time allowances, task essentiality, and extra work requirements (overtime).

In all of these models, an analysis of the task or mission to be simulated is required prior to simulation. This analysis provides input data to the computer. These data, together with information on equipment, personnel, emergencies, and the like are prepared for computer processing in accordance with a program which implements the model's logic. Under program control, the computer starts at mission time zero and simulates the crew's performance of each unit of work or occurrence during the mission.

To date, it appears that the attempt to include human behavioral and social interactive variables in determining system effectiveness has been limited to the efforts of Applied Psychological Services. No other model currently available attempts to account for and predict human behavior in as detailed and mathematically explicit a fashion. This has been true even though it has been estimated (Blanchard, 1972) that over a 20 year system life cycle, 80 per cent of the cost in that period can be assigned to personnel. It would appear, then, that the need for SR models which include personnel related variables is apparent and that the ISM provides such a framework. Furthermore, the logic of the ISM facilitates the extraction of both equipment related and human related factors as they are involved in system performance effectiveness.

Additionally, it was determined that the ISM could be modified so as to satisfy each of a number of characteristics and properties required in a system reliability oriented model.

The present report describes the entire model including these modifications and as such is self contained. It also presents the extent of success this resultant model has demonstrated in initial model testing simulation runs.

The approach adopted was to take the ISM, which is principally HR oriented, and to augment its basic capabilities with additional features such as:

- operator induced equipment failures
- motion sickness and its effects
- equipment performance measures
- shift simulation capability
- increased tracking of uses of consumables including spare parts
- enhanced summarization so as to yield measures of equipment, human, and system reliability
- simulation of a related group of events, called a "family," to yield increased simulation detail
- generalization of model and extension of limits
- consideration of equipment reliability by four major equipment types
- modification of equipment repair time calculation
- degradation of performance adequacy on emergency and on repair events when such events take longer than a target time to complete

The ISM, as modified for consideration of ER, HR, and SR determination, allows answering questions relative to a specific system such as:

- What is its ER?
- What is its HR?
- Which components of ER contribute most to unreliability?
- Which components of HR contribute most to unreliability?
- What changes in equipment will lead to an increase in ER?
- What personnel changes will increase HR?
- What behavioral variables contribute most to HR?
- What part does ER and HR, respectively, contribute to SR?
- What system design changes will best contribute to an increase in reliability?
- How does crew proficiency affect HR? SR?
- What are the effects of such items as motion sickness, fatigue, morale, level of aspirations, etc., on HR? on SR?

Goals

The balance of this chapter contains a description of the various goals set for the enhancement work in terms of features and characteristics required of the resulting model. General descriptions are also included of the approach taken. Specific information on model logic changes, and their impact on the ISM computer program are presented in Chapter II.

Numerical Estimate of Reliability

Perhaps the most critical requirements of a HR model is the ability to provide a numeric defining HR in a manner which can be compounded with ER data. This compounding should result in a summary numeric defining the total SR. The importance of this property was noted by Blanchard (1972), who summarized the statements of his panel of model users as follows: "There was a concensus (sic) on the desirability of integrating, incorporating, or in some way combining human reliability models with equipment reliability models" and "... attention should be devoted to the statistical compatibility of human error rate data and equipment failure rate data which might in some way be combined to provide an overall output reliability index."

Accordingly, ISM was modified so as to allow separate summary numerics reflecting both the reliability of: (1) equipment (and its "performance" during the simulation) and (2) humans and their performance. These numerics are based on a common metric and, as such, may be compounded to give an overall estimate of SR. The separate identification of the two reliability numerics allows the quantification of the contribution to SR of the two major system components. The results, accordingly, allow identification of the component which might be most advantageously modified so as to provide the greatest improvement in overall SR.

Characteristics of the Numeric

In order to arrive at an overall estimate for ER, traditionally, single component reliabilities are expressed probabilistically and are compounded. An an analogous fashion, it has been suggested that HR be generally conceived as being a composite index. Meister (1970), for example, noted that "... since the reliability prediction (ER) is formulated in probabilistic terms, the HR technique must be formulated in comparable terms." Meister also observed that "... it will be necessary to deal with the likelihood of events occurring over a series of performances." Somewhat more generally, it seems necessary to deal with the set of events which constitute performance as well as over a series of performances of the set. This approach possesses the advantage of identifying the specific components contributing to unreliability which degrade overall HR. System designers, among others, would be able to investigate on an "event-by-event" basis where major improvements either in the man-machine interface itself or in the introduction of some form of performance aiding would best augment HR and, consequently, SR. By an "event" in the HR sense is meant a component of the overall task such as "detection" in a sonar attack sequence.

As a further requirement within this approach, Blanchard (1972) noted in his survey that "... most respondents indicated that... use of single-value performance estimates including HR indices... would be inadequate for their needs." This conclusion was reached from an expressed desire among his respondents for a quantification of the distributions (as well as tolerance limits) surrounding the performance estimates. This desire is analogous to the synthesizing of distributions from component test data as involved in a determination of system reliability, as described by Fagen and Wilson (undated). Similar data for the components, if not for the whole task, in an HR determination would also be desirable.

Accordingly, it seems that the underlying components of HR in a given system should be identified and measured on a common metric (probability of success), allowing both a measure of overall HR as well as the identification of the components of the final index. Distributions of values analogous to MTBF distributions will also be obtained, wherever possible. Where distributions are available, compounding might require convolution of mathematical functions.

Level of Specificity

One of the key issues in HR determination is the level of specificity required. Balaban and Costello (1964) concluded that "There can ... be no general criterion for the level at which a <u>system</u> should be defined; nor can general ground rules be formulated. Each assessment must dictate its own criteria." Likewise, no uniform agreement among model users on this important question was found by Blanchard (1972).

Dunnette et al. (1972), in discussing the issues involved in the development of a Naval Personnel Status Index (NPSI) raised a problem somewhat similar to that considered here--the level of specificity necessary for the development of an index of HR. They suggested that the basic data system necessary for the development of their NPSI should focus on tasks or functions as the primary unit of analysis. In view of the difficult effort involved in the development of a data store type of system and possible user resistance to its employment (Blanchard, 1972), the HR metric focused in its level of analysis on tasks and/or functions. In ER determination, the level of specificity was selected at the equipment level. The ER for maintenance of all types of equipment (electrical, electromechanical, mechanical and electronic), as well as for equipment operation, was also provided for.

Sensitivity and Robustness

While it is desirable that both the overall ER and HR indices of the model be sensitive to shifts in their respective components, subtle shifts should give rise to small or no changes in the major index. In general, each index should be robust to minor day-to-day fluctuation in magnitude and/or direction of their components. Additionally, changes in the index should not be time dependent in and of itself (Bryan, 1973).

Model Reliability, Validity, and Generality

The first requirement of any model is that it be reliable; that is, its predictions must be stable. With stochastic models, this stability is reflected in the distribution of obtained values being consistent over different model runs. Following the establishment of model reliability, model validity can then be ascertained. Validity is defined as the demonstration that a model is measuring what it purports to measure. With stochastic models, predictive validity can be demonstrated when the distribution of model derived values reflect the expected (actual) distribution to within acceptable levels of agreement. Expected distributions can be obtained from historical records, theoretical derivations, etc. Since both reliability and validity are quantifiable constructs, it is necessary to define a model's reliability or validity in a statistical sense. The issue to be considered is one of more or less reliable and/or valid rather than a simple yes/no dichotomous decision. Validity, in the form of success or failure of performance, however, must be clearly stated (Meister, 1970).

The validity of a model is a function of its generality. As generality increases, validity decreases for any given situation. A balance between validity and generality must be forged in most stochastic model development efforts.

Other Goals Established

In addition to the properties and characteristics noted above, other features mentioned by others were established as desirable objectives in enhancing model utility. First, a model should be easily utilized by nonspecialists (Meister, 1970). Input requirements and outputs should be as simple and nontechnical as possible, but experience has shown that models which tend to require a great deal of sophistication on the part of the user have not received wide application. Similarly, model input requirements (e. g., formats) should be set up in a manner that is compatible with both typical engineering and human factors analyses. To the extent that a model exhibits parallel structure in its requirements for engineering and human input data, the less complicated will be the input data task requirements.

To the extent possible, a model should make use of available data or data which can be developed from usually available data via transformations. Once again, the less the burden on the model user, the greater is the expected use of a model.

Additionally, a goal was established to develop a model general enough to be applicable during system development, as well as during final system performance assessment (Siegel, 1973 ; Leuba, 1968; Meister, 1970). This use of a model will probably be critical in evaluating overall utility. As Blanchard (1972) has noted, one of the most frequent problems facing Navy planners is deciding between two (or more) alternative systems while the systems are in early planning stages. The model should allow planners in the early phases of system development to compare relative reliability or values of some similar effectiveness measure for competing systems.

Finally, a model should include consideration of qualitative and quantitative manning requirements so as to allow testing of expected performance levels of crews of different skills and proficiencies within skills.

Fleishman et al. (1973) have observed that "The parallel specification of the elements contributing to human reliability in a manner analogous to that performed for machine components by engineers is a necessary prerequisite for predicting overall system reliability." The adaptation of the ISM is designed to determine the ER and HR components of SR, as well as SR. This approach clearly follows that specification, as development of the ER and HR numerics, involves determination of aspects, properties, and characteristics of each. It also involves determination of how these can be dealt with in a parallel manner and their final integration into predicting SR without violating the typical assumptions underlying each.

Further Relationships Among the APS Models and Related Efforts

One question which might be raised is that of the relationships or continuity of variables from one model to another in the series of three Applied Psychological Services' models described. In an attempt to respond to this, and to indicate the relationship of the variables in the ISM to the others, the following summarization presents the principal variables, functions, or concepts of each of the three models.

Although no specific experiments have been performed to determine the continuity of predictions made by the three models due to their similarity, it is expected that reasonable output overlap and trend similarity would result if the same mission could be simulated on the different model.

		Small Model	*Intermediate Model*	*Large Group Model*
PERSONNEL	*Quantity*	1 or 2 men	3-20 men groups group leader	10-99 men groups crew size increment
	Categories/ types		primary/secondary specialties 10 personnel specialties and cross training command echelon	30 personnel specialties and cross training ranks/rates & promotion
	Goals	goal aspiration	aspiration leaders expectation performance adequacy	proficiency deviation leaders expectation
	Physical Attributes		physical workload motion sickness hazard (safety index) sleep physical incapability (sickness) physical workload	confinement sickness
	Performance Attributes	stress and stress thresholds cohesiveness individuality (speed) factor	competence fatigue pace stress and stress threshold mental load unmanned station hours	proficiency orientation morale and morale thresholds cohesiveness unmanned station hours
MISSION	Composition	1-300 tasks	200 events per day of 300 types	1-200 action units per day
	Duration	minutes-hours mission time limit	hours to 30 days shifts	to 30 days shifts
	Environment		sea state	environmental efficiency
	Elements (tasks)	essentiality types (joint, equipment, decision, cyclic) precedence (task and time) execution time success/failure determination waiting, idling success probability time remaining	essentiality types (scheduled, emergency, repair) precedence (task and time performance time fixed and variable event times fixed and variable event times touch up or repeat completion time limit	essentiality types (normal, training, difficult) precedence (time) performance time carryover if incomplete touch up or repeat completion time limit

EQUIPMENT	Quantity		30 types	35 types at 20 stations
	Capability	equipment tasks	failure and generation of repairs operator initiated failures	failure and generation of repairs
	Performance/ Status		failure rates up time down time performance level consumables levels	failure rates communications
OUTPUT MEASUREMENTS	Mission Effectiveness	mission success probability performance repetitions peak stress tasks mission duration	system reliability level system performance level equipment performance efficiency system global effectiveness level consumables balances equipment and human MTBF & MTTR	total efficiency
	Time Utilization	tasks failed, ignored average time used waiting time average time overrun peak and average stress number of tasks and last task completed	success, idle, sleep, repair no. of events, success, fail, ignore, primary, secondary	hours worked, ot, unused, repair no. of action units, repair, ignored essential, nonessential, postphoned
	Personnel	goal aspiration performance average cohesiveness	performance adequacy physical and mental load health and safety indices performance	psychosocial efficiency crew cohesiveness index total crew efficiency sick days crew orientation promotions
	Report Frequency	task, mission iteration, and run summary	event, day, mission iterations, and run summary	action unit, day, mission iteration, and run summary

Principles Leading to Quantification of Variables

Since the ISM is an elaboration of an extant model and its foundations have already been documented, this report will not dwell on the mechanics of selecting or quantification of the model's variables. Siegel, Wolf, and Fischl (1969) present an extensive discussion on the following variables within the model:

physical capability
competence
fatigue
physical incompatibility
working pace
level of aspiration
psychological stress
confidence

This prior work includes literature references to studies considered pertinent and includes full descriptive and analytic logic. Particularly significant relationships are described and instances of agreements of concepts with specific literature sources are cited.

Briefly, the general policy followed in the selection and utilization of variables for use in the ISM, as well as the other APS models, is summarized by the following:

1. from the principal features of the model and its known goals, select one or more theories/approaches of greatest importance, e.g., small group theory, environmental considerations, extent of importance of equipment performance

2. with these guidelines, select specific variables on the basis of literature studies, prior model results, and/or best judgment

3. identify those factors on which selected variables should depend, i.e., the relationships among variables

4. extract from the literature the qualitative analytical expressions which link the variables one to another, fitting trend lines to known or estimated relationships

5. scale the variables and expressions to achieve consistency throughout the model

CHAPTER II

THE MODEL AND THE VARIABLES SIMULATED

Introduction

The model makes provision for simulating characteristics of the individual crew members of a system and the equipment they operate. Each characteristic is altered as a function of events that transpire during a simulated mission, and each in turn exerts an influence on mission events. In general, the HR oriented characteristics subsume physical and mental performance factors, personality and motivational factors, learning and reinforcement, and aspiration and leadership.

A crew of 4 to 20 men is modeled. The ER factors include equipment repairs by type, sea state, intermittent failures, up and down time factors, and equipment performance measures. The activities to be assigned to and performed by the crew are itemized into specific events for each day of a multiday mission. This information, together with data on average personnel performance, on equipments to be operated, and on emergencies which may occur, are provided in coded form to the high speed digital computer. These data are manipulated for each scheduled event, each equipment repair event (or event family), and each emergency which is encountered. The major segments of the model are:

1. crew formation

   identification of each crew member and assignment of specific capabilities and characteristics to each crew member

2. daily schedule generation

   preparation of itemized events to be completed on each day of the mission

3. personnel assignment

   selection of individual men to accomplish the work of each event with option to use a shift assignment logic

4. event simulation

   calculation of conditions existing during each event and the determination of how well and how quickly the assigned men accomplish the work which constitutes the event

5. <u>personnel update</u>

modification of the numerical status of human and equipment variables as a result of group performance during the event

6. <u>results recording</u>

selection and display of the value of key variables and summarized conditions as desired (i. e., for each event, each day, each mission iteration, and a summary of all iterations)

Figure 2-1 presents a gross view of the flow logic sequencing. A more detailed logical flow diagram of the model is included as Appendix C. The two flow charts are compatible in that the key nodes, identified by circles containing lower case letters, represent corresponding points in the model and program. The computer program, written in the FORTRAN IV language, implements these flow charts and the sequenced logic, as described. To facilitate both descriptive and analytic program-to-model interaction, this report will utilize FORTRAN variable names. Appendix A to this report presents a list of the variable names and definitions.

Missions of durations of up to 30 days can be simulated. A mission to be simulated may be composed of up to 300 types of events, and 200 of any of these types may be scheduled on any given day. The events are performed by crews of no more than 20 men who are in up to 10 different personnel specialties and who may be in four command levels. The crew may operate up to 30 types of equipment and may encounter up to 10 types of emergencies. Events are performed by from 1 to 20 men selected from the crew (or shift) to form a group which accomplishes the specific event.

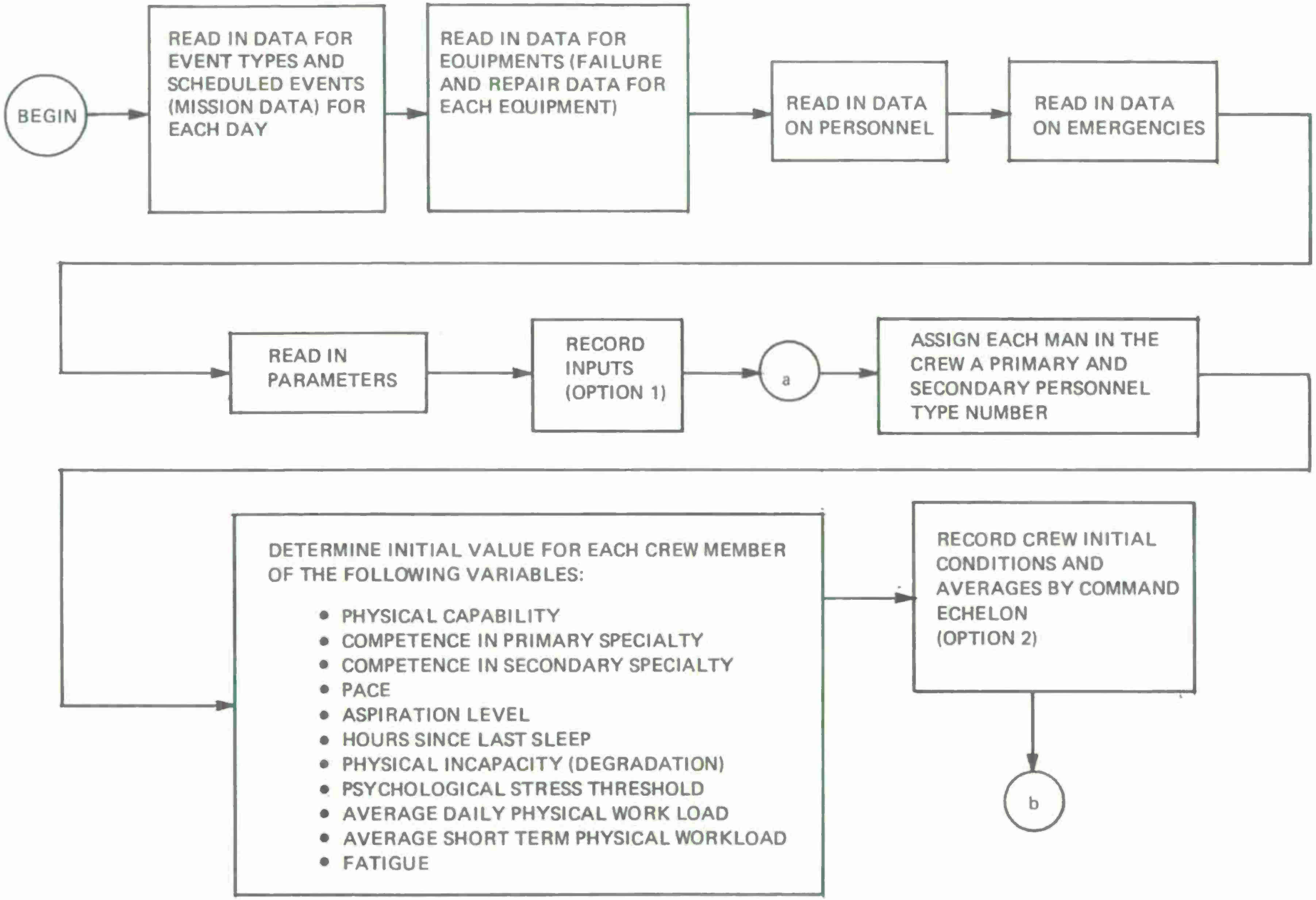


FIGURE 2-1. GENERAL FLOW LOGIC DIAGRAM OF MODEL

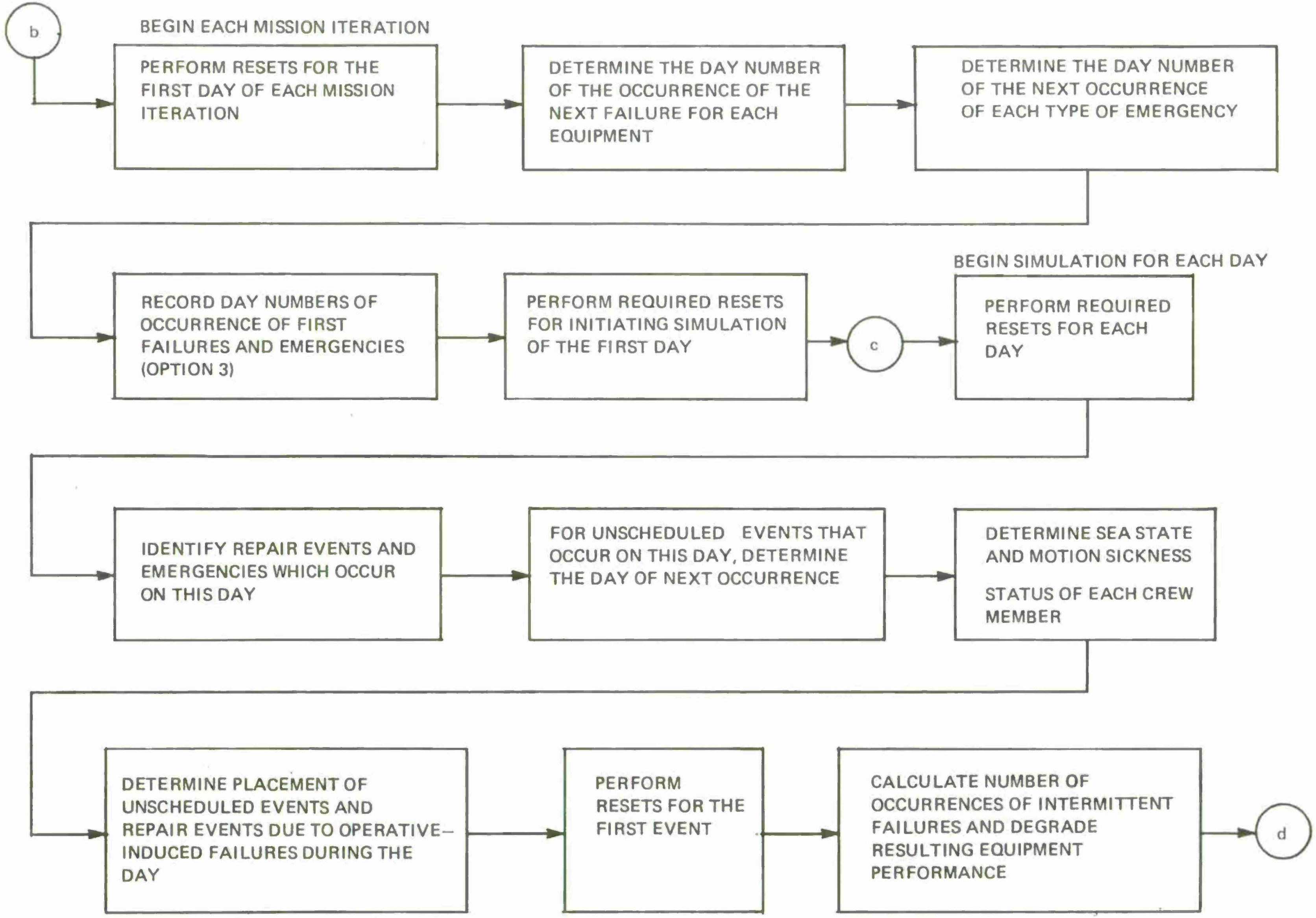


FIGURE 2-1. (CONT.)

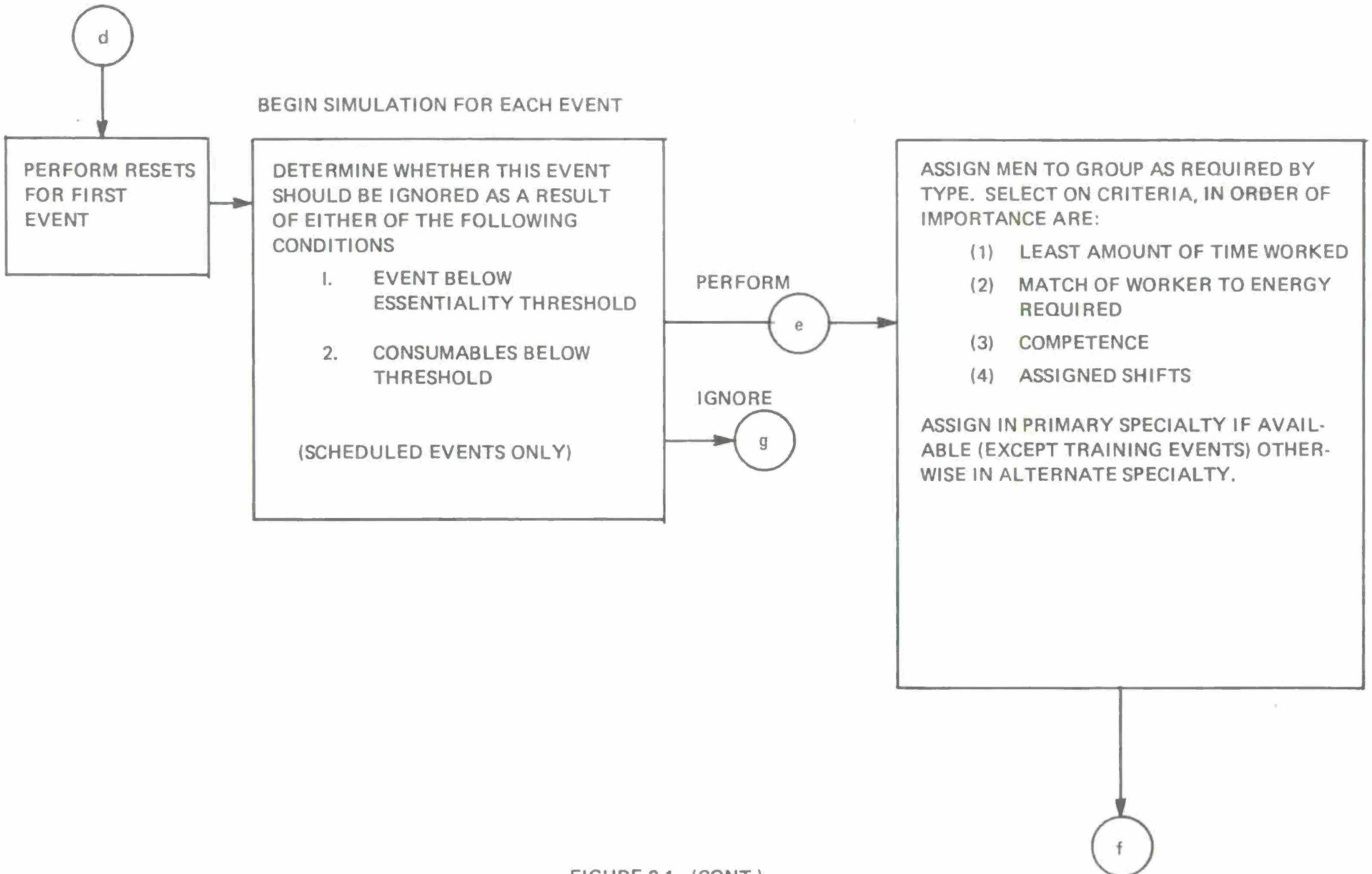
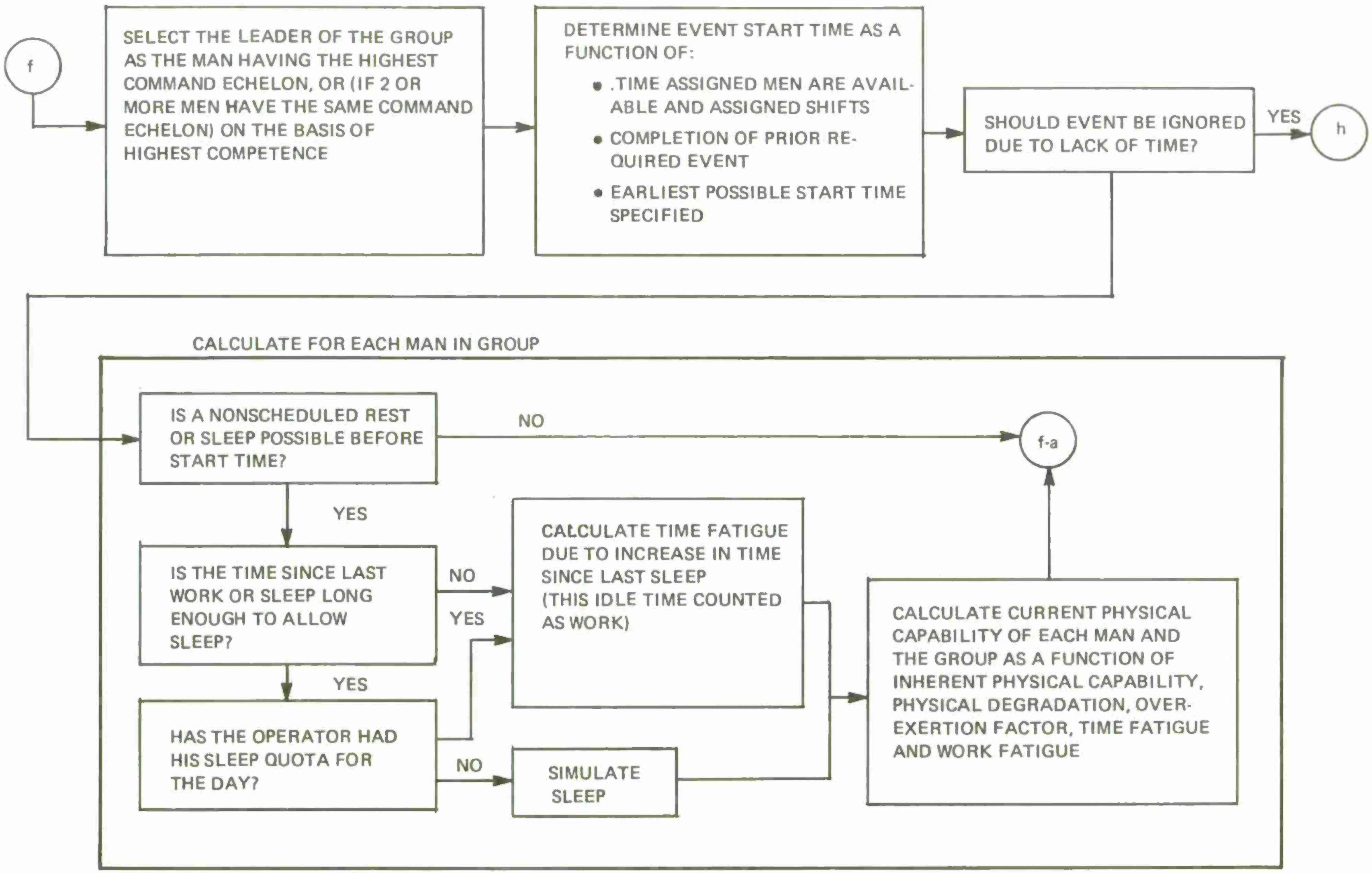


FIGURE 2-1. (CONT.)



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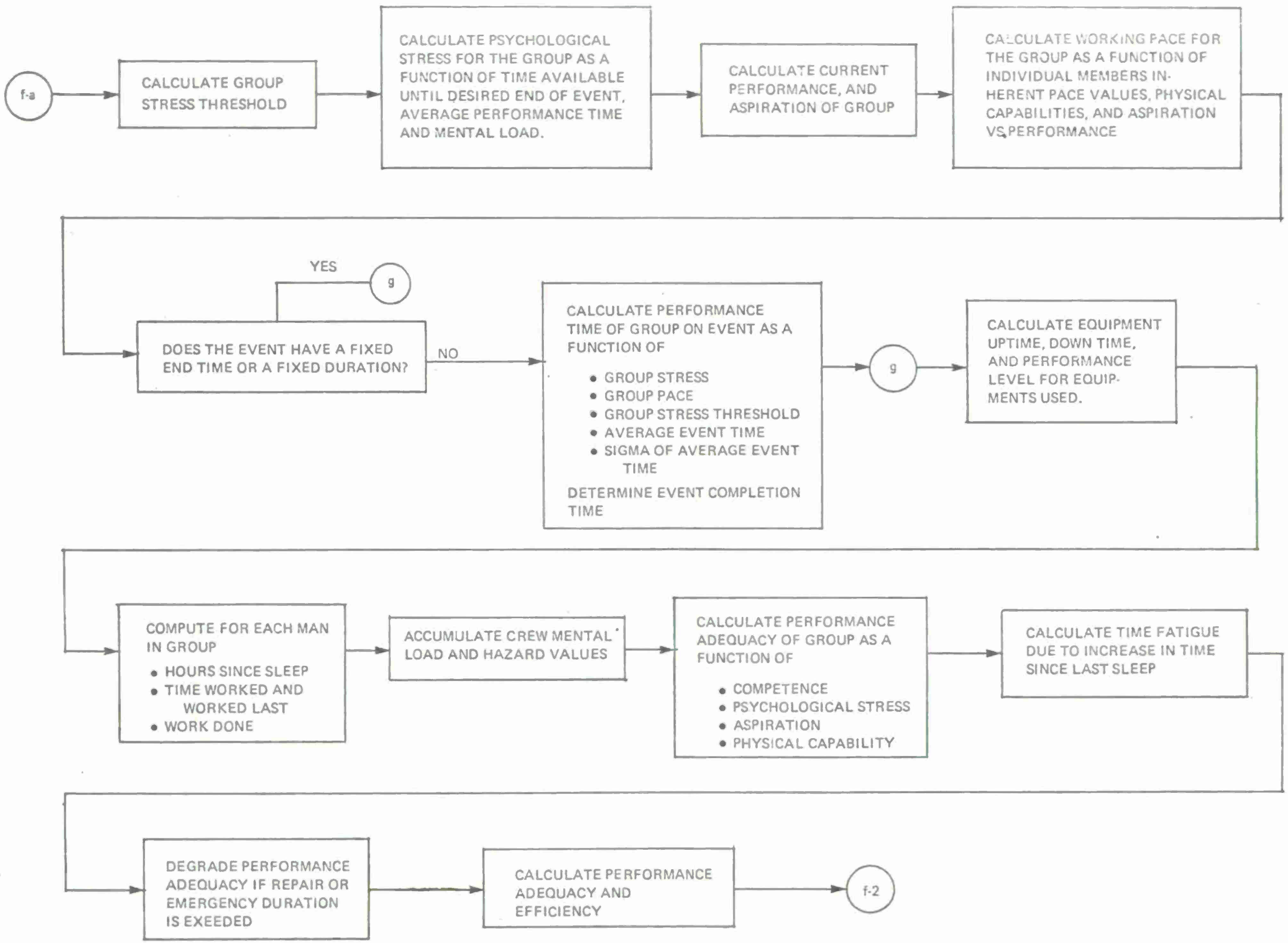

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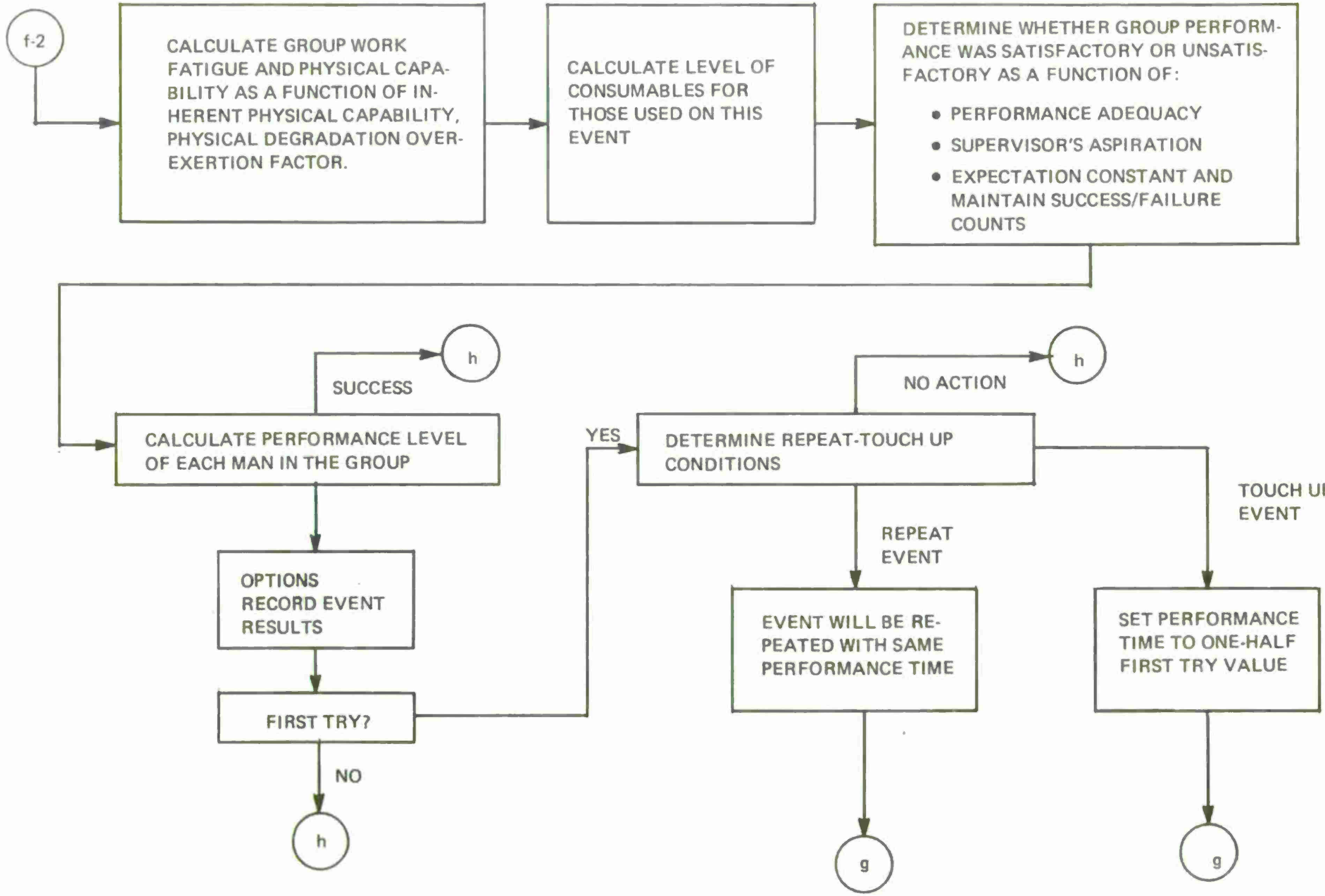

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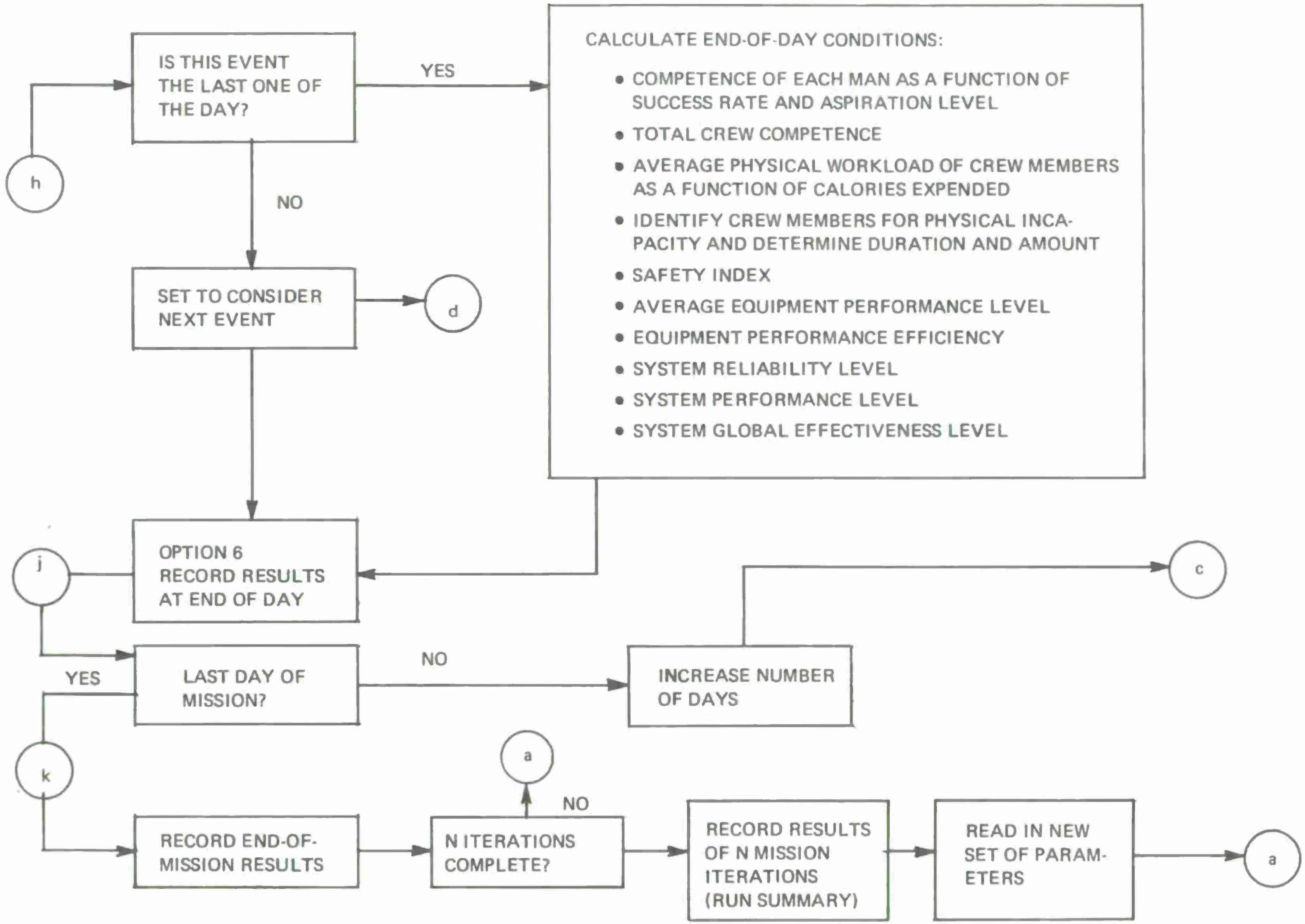


FIGURE 2-1. (CONT.)

Data Input Required

Six sets of data are required prior to use of the model. The individual items of data in each of these sets are given in the various tables in Appendix B. A change was made in the method of handling scheduled event data. Instead of providing input data for up to 80 events each day, the model was expanded and generalized to allow the task analyst to specify (and provide input data for) up to 300 event types. Any of these can be scheduled at any time of any day. The input data for event types is defined in Appendix B. Also, for each day of the mission, the task analyst develops event sequence data for up to 200 scheduled events planned to be performed that day. These task sequence data, specified in Appendix B (each referring to one of the predefined task types) constitute the crew daily workload.

All times in the simulation are given to a precision of hundredths of an hour. Each 24 hour day is simulated, and time is counted from 0000 to 23.99. A subset of the data items for scheduled events is required to describe an unscheduled repair of an equipment or to describe an occurrence of an emergency. Repair events are also called out by type of event.

Note here that the model now distinguishes between incidence of hard equipment failure (a condition in which the equipment is completely inoperable as a result of, for example, a component failure) and the incidence of intermittent failure (a condition in which no "repair" is accomplished but which results in a reduction of performance "score" for the equipment).

The next set of data, relating to personnel characteristics and qualities for the mission, consists of the elements itemized and described in Appendix B. The first is average population body weight (WT). If a specific system is being simulated in which the body weights of its personnel are known to differ from those of the general population or the general military population, the mean weight and standard deviation of that specific system's manning tables become the input data. For all other circumstances, the mean weight and standard deviation may be obtained from any appropriate anthropometric tabulation (e.g., Damon, Stoudt, & McFarland, 1966; Webb, 1964; Hertzberg, Daniels, & Churchill, 1950; etc.). The crosstraining probability table provides the likelihood values of a man of each type having been crosstrained in each secondary specialty.

Appendix B lists the parameters of the model. This model monitors the level of up to 20 selected consumables. Of these 20, 10 may be monitored on a unit expenditure basis and 10 may be monitored on a rate of expenditure (e.g., 100 gallons per hour) basis. One parameter input specifies the initial inventory of consumables at the beginning of the mission in arbitrary units. A secondary input specifies the consumable threshold values. When the value of one or more consumables drops below the selected threshold, those events which require this consumable (except repairs and emergencies) are ignored. The parameter N provides for preselecting the number of simulations to be performed. Other parameters are described later in this chapter as their influence is noted during the processing flow.

FORTRAN nomenclature for other data items, constants, arrays and variables complete Appendix B. Discussion of recordings of results in various print-out options is postponed to the end of the event simulation discussion.

Crew Formation and Initial Value Selection

The processing begins at circle a of Figure 2-1 or Appendix C. The number of men in the crew is determined totally and by command echelon using the MEN [NT, ICE(M)] data provided as input from the personnel data. Each man is assigned to one of four command echelon values:

1. officer
2. senior petty officer
3. junior petty officer
4. unrated

Then, each crew member is assigned a primary specialty or type number, IPS(M), by the computer. Next, using this assignment and the personnel crosstraining table, PTT[IT, IPS(M)], from the set of personnel input data, each crew member is assigned a secondary specialty, ISS(M). Values of IPS(M) and ISS(M) range from one to 30, corresponding to the 30 possible types of personnel.

Crew members of different levels of physical capability are simulated. The physical capability variable, as employed, is intended to summarize and represent the physiological/anthropometric characteristics which the crew member brings to his job.

A normalized physical capability value, PC(M), is now assigned to each man. It is the beginning of the mission value calculated using the mean and sigma of body weight of the total population (personnel input data) based on a normal distribution. Here, as well as elsewhere in this report, RD denotes a random deviate, i. e., a number drawn at random from the normal distribution with a mean of zero and a standard deviation of unity. A crew member of average weight will have a value of PC(M) = 1.

The parameter CALRY represents the energy consumption of the average crew member in a day. Using each man's normalized body weight as a multiplier with the parameter CALRY, a specific value is calculated indicating the average number of calories, CAL(M), which each man normally could be expected to expend each day. A similar but short term value of energy or power output (consumption) rate, PWR(M), is calculated for each crew member, again using PC(M) as a multiplier. The parameter PWRRT, the average caloric expenditure of all crew members over a strenuous one hour task, is multiplied by the physical capability value PC(M) for each M, and the result PWR(M) is used as the short term power rate per hour. (See bottom-right box of Appendix C, flow chart sheet 1.) PWRRT (mnemonic power rate) is considered to reflect a short term peak workload requirement.

Values for individual crew member's pace or working speed are selected by pseudorandom number techniques from a normal distribution having a mean equal to the average crew pace parameter, ACP, and a standard deviation of 0.11. That is, 68 per cent of the crew population can be expected to fall in the range from ACP - 0.11 (fast operators) to ACP + 0.11 (slow operators).

In a similar way, the model next calls for the calculation of a value representing the level of aspiration, ASP(M), for each crew member at the start of each mission. These are selected from a normal distribution with a mean equal to the input parameter AASP and a standard deviation equal to one-tenth of that value. ASP(M) values must fall in the 0-1 range.

The amount of sleep each man takes each day is monitored by the model as a factor influencing fatigue. One of the elements involved here is the length of time since the completion of a crew member's most recent sleep, HSLS(M); the mnemonic is hours since last sleep. In order to determine an initial value of this variable for each man at the beginning of the mission, the Monte Carlo method is again employed where the average is the input parameter, SLEEP, and the standard deviation is 1/4 SLEEP. Thus, this initial HSLS(M) value represents the number of hours since the last sleep of a man, M, at the start of the mission.

Given values for HSLS(M) for every crew member, it is then possible to determine the fatigue level for each man, FAT(M), an important mission starting condition. This is accomplished using the subroutine FBUILD (fatigue buildup) shown in Appendix C.

The next initial condition calculation for the crew results in the selection of a stress threshold for each man, STRM(M). Again, a specific value is taken for each crew member from a normal distribution having an average equal to the average psychological stress threshold parameter, APST, and a standard deviation of APST/6.

The model next generates a value for competence of each crew member in both his primary and secondary specialties, PCOM(M) and SCOM(M), using subroutine PSCAP, Appendix C, page 22. Competence is a descriptive variable for affording gross categorization of the quality level of an individual's criterion behaviors. This is accomplished by command echelon using percentages of crew of various qualifications as provided in the personnel input data, and the summarized crew complements by command echelon, IAA(CE), previously calculated. The total crew competence is determined in the primary specialty as an average of the PCOM(M) values over the crew.

Any physical incapacity, PI(M), of a man at the beginning of the mission is calculated next in the same way in which it is determined before beginning each day's simulation. A few randomly selected men may have a degraded condition representing mild sickness. The number of such men to be so degraded each day, NPI, is determined by selecting a number from a Poisson distribution whose average is the quotient of the number of men in the crew divided by the parameter MPI (the average number of man days per incidence of degradation). For example, if there are 15 crew members and degradation is expected, on the average, once out of 10 man days, then the number of men considered handicapped is selected by drawing a number (always an integer) from the Poisson distribution having an average of 15/10 = 1.5. The selection of which specific individuals are considered to be degraded is made randomly so that all men are equally likely for selection. For each man, M, so selected, the model calculates the level of incapacitation, PI(M), and the duration in days[PI2(M)].

The level of physical incapacitation is calculated so as to yield an equiprobable value in the range from 0.75 to 0.95. Similarly, the duration of the degradation is determined from a Poisson distribution sampling in which the average value is PID, a personnel input datum representing the average duration of a minor physical incapacitation. The model does not simulate the situation in which a man is incapacitated to an extent which precludes his working.

The results of all initial value selection computations are optionally recorded (print option 2, IND(2) = 1) individually for each crew member and summarized by crew echelon and for the total crew. A sample of these data is shown in Table 2-1.

Table 2-1

Sample Computer Output for Initial Values

APPLIED PSYCHOLOGICAL SEPVICFS--NAVSEA HURT AIS,MRL,JJW,JB   11/05/74   PAGE 7

PRINT OPTION TWO

CE	PC	PCOM	SCOM	PACE	ASP	HSLS	PI
1	1,156	0,949	0,990	1,056	0,779	1,079	1,000
2	0,969	0,920	0,931	1,089	0,895	1,014	1,000
3	1,056	0,958	0,965	0,958	0,905	1,204	1,000
4	1,035	0,937	0,946	0,973	0,822	0,871	1,000

IC	PC	PCOM	SCOM	PACE	ASP	HSLS	PI	PI2	FAT	STRM	CAL	PWR	ICE	IPS	ISS
1	1,202	0,920	0,990	1,211	0,740	1,234	1,000	0	0,103	2,571	3245,	528,804	1	1	5
2	1,110	0,977	0,990	0,901	0,818	0,924	1,000	0	0,102	2,570	2998,	488,573	1	1	3
3	0,917	0,930	0,935	1,191	0,805	1,254	1,000	0	0,110	1,792	2475,	403,341	2	3	8
4	1,021	0,910	0,926	0,986	0,986	0,775	1,000	0	0,	2,810	2758,	449,448	2	4	1
5	1,134	0,925	0,975	1,070	0,858	1,368	1,000	0	0,111	2,990	3061,	498,883	3	6	4
6	0,968	0,982	0,983	0,868	0,877	1,146	1,000	0	0,044	2,002	2614,	425,974	3	7	5
7	1,066	0,966	0,936	0,937	0,980	1,097	1,000	0	0,112	2,049	2877,	468,920	3	8	8
8	1,124	0,940	0,940	1,045	0,888	0,737	1,000	0	0,	1,959	3036,	494,741	4	9	6
9	0,945	0,934	0,951	0,901	0,756	1,005	1,000	0	0,019	1,632	2550,	415,635	4	10	8
AVGS/MAN	1,024	0,943	0,959	1,012	0,856	1,060	1,000	0,	0,067	2,264	2846,	463,813			

Preparations for Daily Simulation

At circle b of Figure 2-1, several variables are reset to initiate the simulation. These resets precede the simulation of the first day's events.

In preparation for simulation of all daily events, the model now calls for the determination of the specific day of first occurrence of any repair (due to catastrophic failure) of each of the IQ equipments, as well as of the day of first occurrence of each of the K types of emergencies. There is a limit (including up to 10 operator induced failures) of 30 repairs per day. The dates of first repair are based on an exponential equipment failure distribution. These are calculated as one would determine the time of arrival of an event so distributed. (Note that the model critically determines the day of first occurrence of each failure. Later, each time a day is simulated in which such a failure occurs, the same procedure is used to determine the day of next occurrence of the failure. The method selected is from Bekey and Gerlough (1965):

> A phenomenon characterized by sequences of arrivals may be treated by the exponential distribution; then:
>
> $$p(g \geq t) = e^{-t/K}$$
>
> expresses the probability that spacing between arrivals equals or exceeds the specified time, where g = gap between arrivals, t = time, K = average time spacing between arrivals and 1/K = arrivals per unit time. Then $t = -K\ln(1-P)$. One may substitute a random fraction $R = 1-P$ and solve for the time between arrivals.

In this way, the day of first failure occurrence, IDF(IQ), is determined and rounded to the nearest integer day for each equipment, IQ. The "constant" used, RELH(IQ), is the average time in days between hard (catastrophic) failures of equipment IQ and the equipment failure rate is measured in average number of days between failure occurrences. During the course of the mission, as each failure occurs on a day being simulated, the day of occurrence of the next failure of that equipment is determined as outlined above and added to the previous day's value to obtain the current (next) value.

All IDF(IQ) values are reset to zero at the initiation of each mission iteration.

Determination of the similar day of first occurrence of each of K types of emergencies, IDE(K), is based on the exponential distribution using the above described logic for the time of next equipment hard failure. This was implemented since it was considered that an assumption of a constant hazard rate for anticipation of emergencies was appropriate.

The following brief analysis, although it is a relatively standard derivation, shows that the consequence of this assumption is the exponential distribution.

Let $\lambda\Delta t$ = probability of a random event between t and $t + \Delta t$. Then, $1 - \lambda\Delta t$ = probability of no random event between t and $t + \Delta t$. Let $N(t)$ = probability of no event from $T = 0$ to $T = t$. Then $N(0) = 1$, also $N(t + \Delta t) = N(t) \times (1 - \lambda \Delta t)$. That is, no event from 0 to $t + \Delta t$ means no event from 0 to t and no event from t to $t + \Delta t$. From this equation, we can obtain a differential equation, solve it, and so obtain the exponential distribution of time between events:

$$N(t + \Delta t) - N(t) = -N(t)\lambda\Delta t$$

$$\lim_{\Delta t \to 0} \left[\frac{N(t + \Delta t) - N(t)}{\Delta t}\right] = -N\lambda = \frac{dN}{dt}$$

Solve differential equation, using $R(0) = 1$, to obtain:

$$N(t) = e^{-\lambda t}$$

Thus, a constant hazard rate and an exponential distribution of time between events are equivalent.

Daily Simulation

The logic sequence now enters the phase of processing which is repeated serially for each mission day, ND. The sequence is initiated at circle c (Figure 2-1) with reset of several variables in preparation for the daily processing.

Motion Sickness

Next, the effect of sea state on crew performance is determined for the day. The operation of most nonshore based Navy equipment is in an environment where motion sickness can affect human reliability. Motion sickness is caused by particular kinds of motion; its symptoms include nausea, vomiting, malaise, and cold sweating. The incidence of motion sickness on sea cruises varies from less than one per cent to almost 100 per cent, depending on the vessel, the sea conditions, and other factors (Tyler, 1946). During moderate turbulence, a 25-30 per cent rate of sickness to the point of vomiting can be expected (Chinn, 1963). While it is generally accepted that when conditions are appropriate, almost everyone will become motion sick, it has been shown (Hemingway & Gareen, 1945) that the degree of susceptibility to motion sickness varies among individuals. A number of studies have shown that repeated or continuous exposure to motion results in declining motion sickness in most people (e.g., Bard, 1945; Bruner, 1955). It is clear that sufficient empirical data exists to generate distributions of expected motion sickness as a function of mission length. The parameter inputs, SESTA(IS), specifies the cumulative probability of each of 10 values of the roughness of the sea from 0 (calm) to 9 (rough). For example, a value of SESTA(6) = 0.72 indicates that 72 per cent of all mission days have a sea state of six or below. Prior to simulation of each day, a pseudorandom number (RY), in the 0 to 1 range, is compared to the 10 SESTA(IS) input values. Here is the sea state index 0, 1, . . . , 9. For example, if the SESTA(IS) values are:

	0	1	2	3	4	5	6	7	8	9
SESTA(IS)	0.10	0.30	0.50	0.80	0.90	0.95	0.97	0.98	0.99	1.0

and RY is .36, the sea state for this day, ICSS, = 2 since SESTA(1) $<$ RY but SESTA(2) $>$ (RY). The current day's sea state, ICSS, is selected as the minimum value of IS for which SESTA(IS) $<$ RY is selected as the sea state for the current day. This sea state value is used in the calculation of a value for competence of each crewman for the day. Both primary and secondary specialty competences, TPCOM(M) and TSCOM(M), are affected. The effect is linear such that no change to previously computed, nondegraded (start of mission) competence values is made if IS = 0 (calm sea) and such that start of mission values are degraded by a factor of 0.445 for a worst case of sea state of 9, representing a heavy storm condition. This linear relationship between sea state and competence is shown in the bottom left box of logic flow sheet 4 in Appendix C.

Following this, the list of days of the first occurrence of repairs and emergencies (just calculated) is scanned to identify any repairs and/or emergencies which are to be simulated on this day. (The model provides for simulation of up to 12 "repair" events to represent a single equipment repair.) The total number of such repairs and emergencies is integrated with the events of this day. Pointers, identifying the sequence of events to be simulated, are then generated. If there are no repairs or emergencies, the pointer for event 1 will be 2; for event 2 it will be 3, etc. When a family of one or more repair events or an emergency is encountered in this process, the logic calls for placing this unscheduled event in a random but equiprobable position in the sequence of all events for the day. The pointer for an unscheduled event is calculated by taking the product of a pseudorandom number in the interval 0-1 and the total number of events for the day, NTE. The pointer(s) for the event just prior to the unscheduled event(s) is (are) then adjusted to indicate the unscheduled event. The data for repairs and emergencies are transferred in memory for processing in sequence as determined by the pointers.

This process is accomplished by generating an array of pointers, NPTR(I), I = 1, 2, . . . , NTE, where NTE is the total number of events of all types. Pointers serve to identify the event to be simulated next, after each event. The maximum value of NTE is 570, the sum of NOSE + NR + NE:

NOSE	$\leq$	200:	scheduled events
NR	$\leq$	360:	repair events (30 equipments x 12 repair events per equipment)
NE	$\leq$	10:	emergency events

The pointer array space assignment is then:

0 - 200	scheduled events
201 - 560	repair events
561 - 570	emergency events

The following other data are now automatically inserted for repairs and emergencies:

Kind of event ending	KE	variable end time
Type of event	INT	emergency or repair
Time event must be completed	TL	24 hours (any time)
Time before which event cannot begin	ST	0 hours (any time)

Operator Induced Malfunctions

The possibility of an operator inducing malfunctions into the equipment with which he works has recently been incorporated into the model. At this point in the simulation for each day, specific equipments are identified on which such failures are to occur. Actual event simulations generated by repairs thus involved are calculated and described later.

The logic for this feature is given in logic flow sheet 5 of Appendix C. Essentially, it performs the following functions:

- During the daily schedule generation, it determines the events on which an operator induced equipment failure will occur:

  - This can only occur once per event family.

  - It is a function of the mental load of the event (an input code 1-9), the current sea state (0-9), and a random effect. The probability is highest when the sea state and mental loads assume their highest values. For example, when mental load for the event is low, i.e., has a value less than 3, then an operator induced failure will occur if the ranges of these are:

$$RY1 < \quad 0.001 + \left(\frac{0.001RY2}{4}\right)\left(\frac{ICSS + 1}{10}\right)$$

$$0 \text{ to } 1 \quad (0.001 \text{ to } 0.00125) \quad (0.1 \text{ to } 1)$$

  - The occurrence of the operator induced failure is then directly proportional to the current sea state and occurs with a probability equally likely to fall between 0.001 and 0.00125 times $\frac{(ICSS + 1)}{10}$. For calm sea (ICSS = 0), this reduces to a probability in the range 0.0001 to 0.000125. For ICSS = 2, then it does not exceed 0.00375.

    The probability of occurrence during an emergency is higher than during a scheduled event.

- In the case in which an operator initiated malfunction occurs, the model generates a family of up to 12 repair events to represent the repair of the equipment into which the failure was induced. These are inserted into the daily schedule of events in which the operator induced malfunction occurred.

Such an occurrence has the subsequent effect of lowering equipment reliability by adding events during which equipment will be logged by the model in a down (inoperable) condition.

Scaling has been selected so that the probability of an operator induced failure per event varies for repairs from 0.001 (low sea state and mental load) to 0.0375 (high sea state and mental load) and from 0.08 to 0.10 for emergencies.

Intermittent Failures

As noted above, processing for hard equipment failures results in repair action events and in degraded equipment scores. The concept of intermittent failures provides for equipment down time, which results in worsened equipment reliability measures, but is not considered sufficiently significant to warrant operator repair action.

To incorporate this feature, the model calculates the number of occurrences of intermittent failures each mission day for each equipment, INO(IQ). This is accomplished by selection of a pseudo random number from a Poisson distribution with mean equal to the average number of intermittent failures per 24 hour period, RELI(JET), provided as an input parameter for each equipment type:

JET	Equipment Type
1	Mechanical
2	Electromechanical
3	Electrical
4	Electronic

Using this value of INO and TUI(IQ) (time an equipment is down for an average intermittent failure), the amount of "down time" for each equipment is calculated. These initial daily values of down time for each equipment will be increased later for each repair event, as it is simulated in turn.

Event Processing

After the setting of the event number, IE, to the value of the first pointer and other initializations, the processing has reached circle d and begins a series of processing steps (through circle h) which is repeated for each event to be simulated.

The number of such occurrences, INO(IQ), is then RP[RELI(JET)], as shown in the top-middle box of flow logic sheet 6 in Appendix C.

Following the resets for each event, the computer determines whether or not conditions exist which would justify skipping (ignoring) the current event. In no case is a repair or emergency event ignored; however, either of two general conditions could cause a scheduled event to be so treated. The first is a low value of the input essentiality of the event, IESS(IE). If this essentiality value is less than the essentiality threshold parameter, IET, then the event is ignored. (The task/mission analyst determines the essentiality thresholds on the basis of his understanding of the relative importance of each event to the mission and these values are provided as mission input.)

The second possible condition for skipping an event is too low a level for a consumable. The model provides for L (up to 10) consumables based on usage per event plus L1 (up to 10) consumables based on usage per time. The model also provides (up to 10) sets of 10 thresholds for the supply of each consumable. One set of thresholds is selected by TS(IE) (input data) as applicable to each event and if the value of one or more consumables is less than the corresponding selected threshold, then the event is ignored.

Personnel Selection for Assignments

The logic detailing the selection of the most desirable personnel to assign to each a specific event begins at circle e of the flow chart. In general, the processing logic is similar for both normal events and training events. However, for simulating the performance of normal events, personnel are assigned on the basis of their primary specialty, whereas in the case of training events, the selection is made on the basis of the secondary specialty.

The processing is performed for each personnel type sequentially. All men of the desired personnel type (who have not already worked more hours than the overtime threshold parameter [WORK 2]) are considered and evaluated for selection on the basis of the following criteria:

1. the number of hours worked so far during the day, TW(M). The man who has worked least is preferred. If there is an excess of men, with equal TW(M) values available, of the type being sought, then the selection is made on the basis of

2. a function, CALR, relating the man's peak energy rate (over a one hour period) to the energy rate, in calories per hour, required by the event also normalized to a one hour period. All cases in which the required energy is less than the man's "available" energy are considered equal. The purpose of this selection criteria is to avoid a mismatch between the requirements of the job and the physical capability of the personnel assigned.

3. competence in the primary specialty, IPCOM(M). The most competent is selected first.

Before actually confirming the selection of a given man for assignment to the group which will perform the event, a test is made to determine if the performance of this event would require that the potential group member to work overtime. That is, the computer tests whether or not the current time worked, TW(M), plus the expected (average) event time, ADUR(IE), exceeds the overtime threshold parameter, WORK 1. If the threshold is not exceeded, then the individual who has been tentatively selected is confirmed for group assignment. If overtime is required for this man (for whom it has already been determined that he has worked least), then there are clearly no more desirable personnel of this type available. In this case, an incomplete processing indicator (IPI) is set. Following the processing of all the remaining personnel types, crosstrained crew members are sought to substitute for any primary specialty men who are unavailable because of the overtime requirement. The overtime thresholds including WORK 1 are provided as input parameters so that they may be varied on computer runs and the effects of such variation on output noted. Values of the parameters should be selected on the basis of reasonableness for the mission simulated, reflecting the realities of the work cycle.

The concept of a family of scheduled events (i. e., a group of interconnected and interrelated events) is also included. This is limited, however, to a series of events performed by one man. In case of such a family (of up to 12 events) all will be performed by the same man--whoever was selected by the selection logic for the first event of the family (i. e., if IFOI(IE) = 1, from the event sequence input data).

By this process, one man at a time is selected and confirmed. If, when the most desirable crew member is selected, additional men are still required of this type, then the process repeats. When all required men have been confirmed, or the proper IPI has been set, the sequence of operations is repeated for each successive personnel type required by the event, until the entire required work group has been formed.

If the IPI indicator has been set during the process, the processing continues with the search for personnel who have been crosstrained in the personnel types which were not fully staffed by primary specialists. Should the situation arise in which no more personnel of the desired type are available in the secondary specialty without their working overtime, then a tally is made and cumulated of all such unmanned station hours, USH, based on the number of unassigned men who are required and the average event time.

Group Leader Identification

Provision is made to simulate the influence of leadership on the work group. Later in the simulation, the leader's aspiration and his competence value are used to effect performance. To this end, the model now requires designation of a group leader. Thus, at the completion of the assignment of the required personnel to a given event, the model continues, at circle f of Figure 2-1, with the identification of a leader for the work group. The group member with the highest command echelon value is tagged as the leader. In the event of a tie, the competing man with the highest value of competence in the primary specialty is selected.

Event Start Time

The next question to be answered is: What is the earliest time that the event can begin, assuming the assigned men are to perform the work, and given other input data? It is likely that the men who have been selected for event performance may have completed their previous assignment (or otherwise be available) at different times. So that the event in question can begin when all selected men are available, the latest time of day at which any group member has completed his most recent work assignment is checked. The earliest shift when the job can be accomplished is also determined. To accomplish this bookkeeping, the computer maintains the latest time that each crew member has worked, Z(M), and the largest of these, Z1, (for the men in the work group) is determined. Another constraint which enters into the determination of event start time is the case in which a specified event must be completed before the present event starts. The prior event, IPE(IE), is given in the input data. This is implemented by keeping a value, ZC(IE), for the time of completion of every event as it is completed, and by determining the time of completion of event IPE(IE), i.e., ZC[IPE(IE)]. The last element in the start time determination is a specific time of day before which the current event cannot begin. This value, ST(IE), is also provided as input data. Thus, the event start time is selected as the largest of the three values: Z1, ZC[IPE(IE)], and ST(IE).

If this start time exceeds the input data time limit value, TL(IE), then the event is bypassed after a calculation of unmanned station hours, USH. The USH variable is used to accumulate the number of working man hours which were dictated by the event workload but which are not performed due to unavailability of crew members or the like.

Shift Logic

The optional shift logic allows the division of the total crew into watches (shifts). In the case of implementation of this logic by the analyst, only men assigned to a shift which is congruent with the real time of day are selected for event assignment. To implement this feature, each simulated crew member is assigned by the task analyst to one or more shifts up to a maximum of six shifts in a 24 hour day. The model determines the earliest time an event can begin (based on its start time or time of completion of the specified precedent event), and identifies men for each shift during which the job could be performed. The same man may be identified for more than one shift. The number of unmanned station hours (level of undermanning) which could accrue if the event is performed on each possible shift is then computed, and the event is assigned to that shift in which unmanned station hours is at a minimum. Where the minimum unmanned station hours occur in more than one shift, the earlier shift is selected for event performance. The no shift option can be effected by assignment of all crew members to all shifts by the task analyst.

Event Families

In order to allow for the fine grain simulation/analysis of events, the event family concept was developed. The analyst can break down each scheduled or repair event into a series of subevents. These components of human performance can then be simulated to determine which are most critical to successful event performance. Different types of men can be assigned to these subevents by the analyst allowing for test of different policies. For example, the results of several simulations may indicate that a specific subevent in a repair family is critical and may require staffing by crew members of generally higher proficiency levels or men who are trained in a specific specialty.

The number of subevents and the simulation sequence of the subevents in a family is fully flexible. For scheduled events, the number of subevents is unlimited, while for repair events the number is limited to 12.

Each event or subevent (scheduled, repair, or emergency) must be assigned to a class by the analyst. The classes for scheduled events are: communication, operation, decision, or act. This allows summarization by class at the end of the simulation.

Each repair is designated as one of four major types: electrical, electronic, electromechanical, or mechanical. Siegel and Schultz (1962), using factor analytic procedures, identified nine factors involved in electronic repair. Eight of these factors, as shown below, were expected to be involved in the electronic repairs to be simulated. These results were extended to the other three major classes of repairs (electrical, electro-mechanical, and mechanical) with analogous factor (type) definitions. The analyst identifies which major class of repair he expects to be necessary in his categorization of the equipment involved in an event as either electrical, electronic, electro-mechanical, or mechanical and uses the factor types to define the sequence of actions required to repair successfully the equipment. Any or all may be used and in any combination. Performance of each of these factors will be simulated as a subevent with the concept of a family being employed to include all the subevents for the repair. Summarization by class (factor) then allows the identification of the factors which contribute to task failure, which take the most time, and the like.

A summary of the repair event types and the factors within types follows.

Repair Events	Code	
	Number	FORTRAN
Electronic		
Uses reference manuals	6	EURM
Electronic cognition	7	EC
Electronic circuit analysis	8	ECA
Electronic repair	9	ER
Electronic equipment operation	10	EO
Electronic equipment inspection	11	EIP
Electronic instruction	12	EI
Electronic report	13	ERPT
Electrical		
Uses reference manuals	14	ELURM
Electrical cognition	15	ELC
Electrical analysis	16	ELA
Electrical repair	17	ELR
Electrical equipment operation	18	ELO
Electrical equipment inspection	19	ELEP
Electrical instruction	20	ELI
Electrical report	21	ELRPT
Electro-mechanical		
Uses reference manuals	22	EMURM
Electro-mechanical cognition	23	EMC
Electro-mechanical analysis	24	EMA
Electro-mechanical repair	25	EMR
Electro-mechanical equipment operation	26	EMO
Electro-mechanical equipment inspection	27	EMEI
Electro-mechanical instruction	28	EMI
Electro-mechanical report	29	EMRPT
Mechanical		
Uses reference manuals	30	MURM
Mechanical cognition	31	MC
Mechanical analysis	32	MA
Mechanical repair	33	MR
Mechanical equipment operation	34	MO
Mechanical equipment inspection	35	MEI
Mechanical equipment instruction	36	MI
Mechanical report	37	MRPT

Fatigue

Provision is made within the model to simulate fatigue states. Fatigue is considered to build as a function of the energy demanded by a work event and K the duration of elapsed time since the individual's last sleep. In general, according to Kleitman (1963), fatigue builds up slowly for the first 8 to 10 hours of wakefulness, then it accelerates more rapidly up to 16 hours of wakefulness, the normal retirement time. If retirement is denied after 16 hours of wakefulness, fatigue continues to guild until about 20 hours of wakefulness, the middle of what would be the sleep period. Then, as a function of the body's circadian rhythm, the rate of additional buildup slows quite markedly. The asymptotic maximum is reached at about the 50th sleepless hour, which would represent two consecutive nights without sleep. The literature indicates that "after two successive nights of sleep deprivation the subjects are about as sleeply as they are likely to get... [Kleitman, 1963, p. 226]."

Having determined the starting time for the event under consideration, the question arises: How long has it been between the time each group member's most recent event was completed and the time the current event begins? If this interval is zero, the following processing for sleep, time fatigue, and physical capability need not be performed since no change has taken place in these values, which are also calculated following each simulated event. However, if some time has elapsed (possibly different amounts of time for each group member), then these factors may change and the appropriate processing is performed. If the interval exceeds the catnap rest parameter, CN, for any man, then it is assumed that the man in question was in fact sleeping during the interval. Exceptions to this are: (1) the situation in which a man has already exceeded the maximum daily sleep allowance parameter MAXSL, or (2) the situation in which a man's fatigue level is below the fatigue threshold parameter TFAT. This last condition insures that no sleep will begin for personnel who are not sufficiently "tired." If a sleep period occurs, its duration is tallied as equal to the interval less a fixed sleep preparation and wake-up time (30 minutes)

A value of time fatigue is calculated if sleep is to be simulated. Time fatigue of an operator, FAT(M), is reduced as a function of the amount of sleep and is increased after the duration of the event itself is known. The fatigue relief function utilized was developed previously by Applied Psychological Services (1966) and is presented as Figure 2-2. The general nature of the fatigue relief calculation is to examine the duration of the sleep and to reduce the fatigue level in accordance with a relationship which specifies that eight continuous hours of sleep reduce fatigue to zero. However, to simulate such factors as individual differences in sleep requirements, more and less refreshing sleep, and other randomly occurring and hence unprogramable events, the specific extent of fatigue reduction resulting from a given duration of sleep is selected by a stochastic process from a range of values surrounding the fatigue reduction curve. This is accomplished by

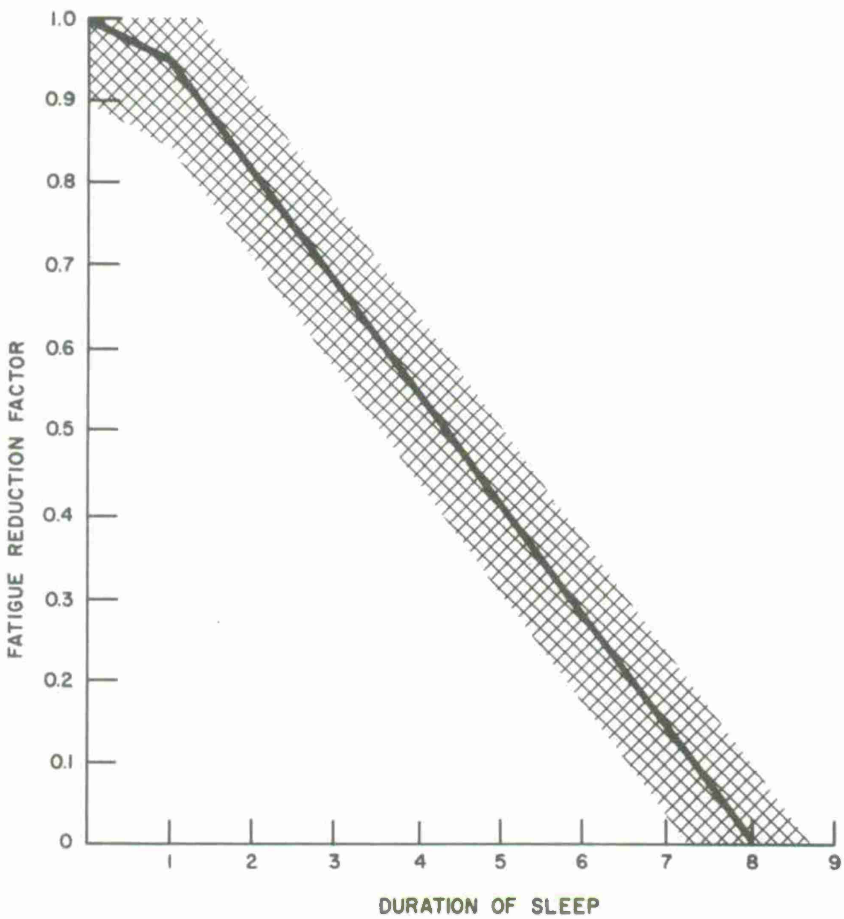


Figure 2-2. Fatigue relief curve.

selecting a number equiprobable in the shaded area (by pseudorandom numbers) around the two linear events in Figure 2-2 as a function of the duration of the sleep period itself. This, in turn, generates a fatigue reduction factor which is then multiplied by the current fatigue level. This process is repeated for each man in the work group independently.

If the interval is insufficient to allow sleep, then it is assumed that the interval was spent in some leisure, recreational or rest activity, but that this activity, nevertheless, has the same effect on a man's fatigue as working. In this case, the model calls for the calculation of a new fatigue value for each group member in this situation. Here, the function used is the fatigue buildup relationship, as shown in Figure 2-3. As in the case of fatigue relief from sleep, the function is divided into linear segments around which random variations are taken to obtain specific values of FAT(M) at any given time. This calculation is self contained in subroutine FBUILD (HSLS), as shown in Appendix C, page 22.

Physical Capability

Salient within the simulation is the conception of the match between a person's physical capability and the job requirements. Heavy duty tasks, such as ammunition handling and equipment moving, require a greater physical capability than operating electronic equipment or plotting courses and bearings. Accordingly, provision is made to simulate individuals of various levels of capability with respect to the physical characteristic of strength.

In addition, the physical capability variable permits the simulation to reflect changes in the same individual. Specifically, this variable affords direct simulation of the effects of fatigue, of such randomly occurring incapacitators as colds, headaches, seasickness/airsickness, sprains and strains, and, as an output, it affords analysis of physical workloads separate and distinct from mental workloads.

The representation of strength in the model is an indirect one. This seems necessary because the literature indicates that strength is not a unitary concept.

Fleishman et al. (1961, 1962) administered a broad spectrum of strength tests to 201 Naval trainee recruits on whom age, height, and certain other data were available. All test results and anthropometric/biographic data were intercorrelated, and the resulting matrix was factored by the centroid method and rotated to a simple structure. This procedure yielded three primary factors of strength, a fourth, markedly weaker, and three final factors not involving strength variables per se (i. e., one was interpreted as a balancing factor, and the other two factors were biographically related). The three primary factors of strength were named Dynamic Strength, Static Strength, and Explosive Strength. They were described by the authors as follows:

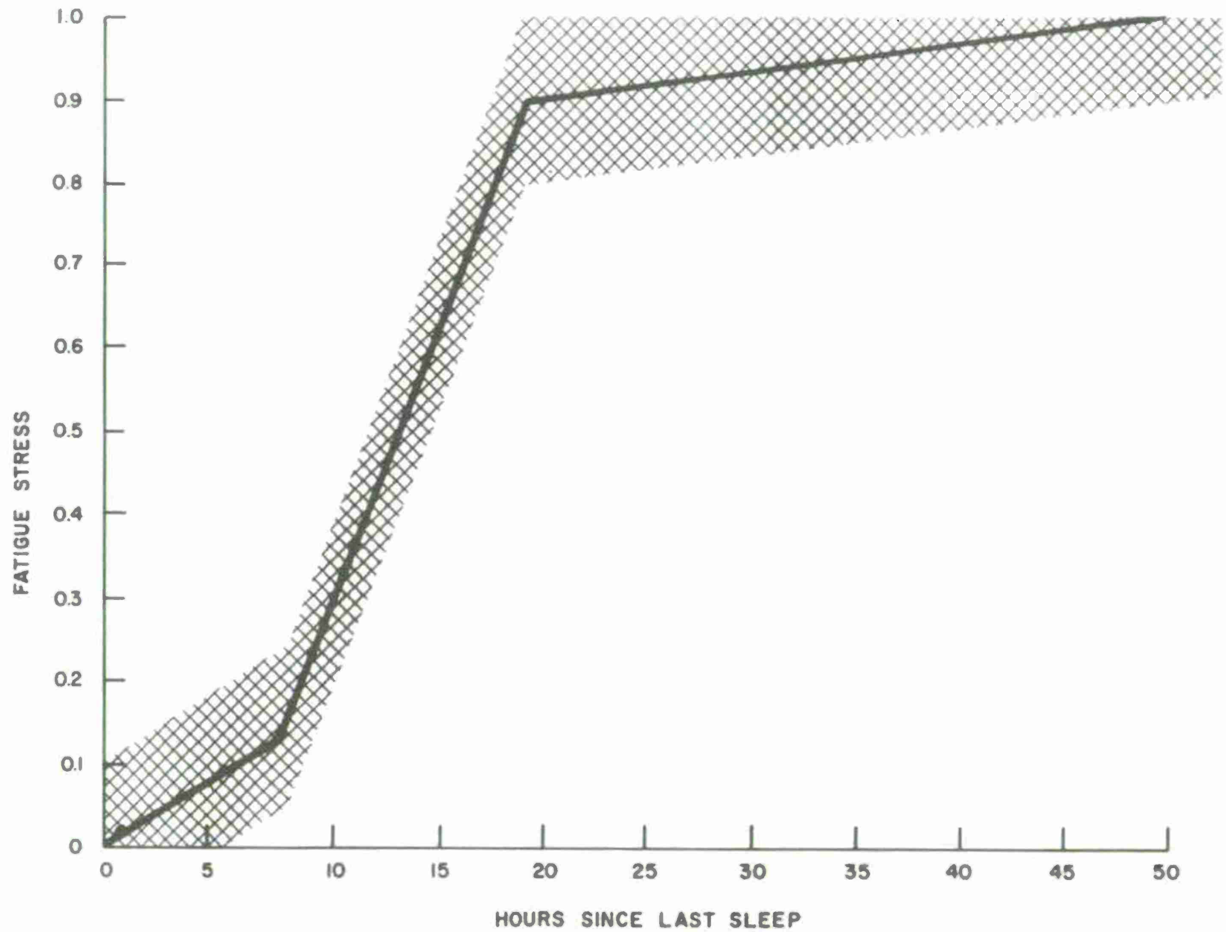


Figure 2-3. Fatigue buildup curve.

> The common requirement of all tests on the Dynamic Strength factor is for the muscles involved to propel, support, or move the body repeatedly or to support it continuously over time.
>
> The tests of our Static Strength factor emphasize the lifting power of the muscles or the pounds of pressure which the muscles can exert. . . . In contrast to Dynamic Strength the force exerted is against external objects, rather than in supporting or propelling the body's own weight.
>
> We have given the Explosive Strength factor the alternate name of "Energy Mobilization," since tasks of measuring this factor require the effective release of energy in one explosive act. . . . The fact that our sprints are loaded on this factor is entirely consistent with this notion of "distance through which a force" can be moved (Fleishman, Kremer, & Shoup, 1961, p. 37).

These descriptions seem to imply that the first and the third factors pertain mainly to the types of strength exhibited in particular athletic contests. In fact, gymnastics and calisthenics loaded most heavily on the first factor and running and jumping activities loaded most heavily on the third. Factor two, however, the so-called Static Strength factor, seems to transcend athletics and to reflect the type of strength involved in most military and industrial laboring tasks which depend on strength. This is the type of strength that is involved in lifting, pushing, pulling, and otherwise moving equipment, and other objects. Furthermore, the Fleishman et al. data show static strength to be highly correlated with weight.

In view of the availability of weight data, body weight was accepted as the indicator of physical capability within the model.

Other data further support the defensibility of weight for providing a reasonable index of strength. For example, Damon, Stroudt, and McFarland (1966) indicated that "A general size factor, common to all dimensions, extends also to strength." Tappen (1950), in examining championship weightlifters, obtained a correlation coefficient of 0.85 between body weight and the number of pounds "pressed." Caldwell (1963) reported a product moment correlation of 0.74 between the weight and the maximum dynamometric pull of both male and female college students. Fisher and Birren (1949) also reported significant correlation coefficients between the dynamometer score and weight of 90 male military personnel and 161 Waves. Hansen and Cornog reviewed a study by Jones (1947) indicating that ". . . strength is related both to body size (especially to weight) and to the mesomorphic component in body build" (Hansen & Cornog, 1958, p. 250).

Within the simulation, the physical capability of the various crew members changes during the course of a mission as a function of two fundamental concepts: (1) the physical capability of the infirmed operator (e.g., the operator who is seasick, has a cold, or a headache, etc.) is less than the physical capability of that operator when he is well, and (2) the physical capability of the fatigued operator is less than the physical capability of that operator when he is "fresh."

By program action, such degrading effects occur at random times during the mission, at a rate dependent on an input parametric value. The processing of this variable occurs, however, only at the beginning of the mission and at the end of each mission day. The value of the variable is utilized in the physical incapacity calculation.

When a simulated individual becomes subject to the incapacity effect, his physical capability is reduced. The exact extent of impairment cannot be specified in view of large individual differences in reaction to these minor ailments and afflictions. Accordingly, the capability reduction is treated by a stochastic process.

Physical Capability Calculations

If a fatigue calculation is required (and a new time fatigue value, FAT(M), determined for the working group members), then the current physical capability, PCC(M), must also be calculated since PCC(M) is dependent upon FAT(M). This calculation represents the physical capability of the men at the start of the event. It is repeated for each group, as described below. It is assumed that the physical capability of a man decreases with time at work, total work done, overexertion, and disability (physical degradation). Physical capability also varies among men. These effects are assumed to be independent of each other and operate multiplicatively. The function* may be expressed analytically as:

$$PCC(M) = PC(M) \cdot PI(M) \cdot \left[1-(1-K1)\left(\frac{ACAL(M)}{CAL(M)}\right)^2\right] \cdot g\left(\frac{P_T}{P_N}\right) \cdot [1-0.1\,FAT(M)]$$

Here, PC(M) is the physical capability (related to strength) of the man, as calculated at the beginning of the mission (1 is an average value). PI(M) is the physical incapacity value related to minor sicknesses discussed above. The factor $[1-(1-K1)\left(\frac{ACAL(M)}{CAL(M)}\right)^2$ is termed the work factor. Here, ACAL(M) is the total work done

---

The physical capability variable was selected and quantified on the basis of an analysis of the pertinent sources as summarized in Siegel, Wolf, and Cosentino (1971, pages 31-34). The form of the function and its rationale follows from that analysis.

(calories expended) on all events from the last sleep period up to and including half of the calories expected to be expended on this event, maintained by the computer as the tally of accumulated calories. CAL(M) is the average number of calories expended in a normal working day for each man, as discussed earlier. The K1 term represents a disability factor--a fraction to which the work factor falls when a particular man has done his normal quota of work during the day. In this analysis, we note that a man's capability decreases as he continues to work and that it is reduced to the value K1 after a normal day's effort. The term $g(P_T/P_N$ represents an overexertion effort. Here, a mismatch of capabilities between the men assigned and the physical requirements of the events, in terms of energy (calories) required, are considered. The function is:

$$\frac{P_T}{P_N} = \begin{cases} 1 & \text{when } P_T/P_N \leq 1 \\ \dfrac{c - P_T/P_N}{c - 1} & \text{when } 1 \leq P_T/P_N \leq c \end{cases}$$

Thus, the overexertion factor has no influence as long as the work rate for the given event does not exceed the peak work rate expected for the men.

In FORTRAN notation:

P_T,	work rate for the event	= IEC(IE) calories per hour
P_N,	peak work rate	= PWR(M) calories per hour
c,	value of P_T/P_N yielding zero physical capability due to overexertion	= ZPC

The function is represented graphically as shown in Figure 2-4.

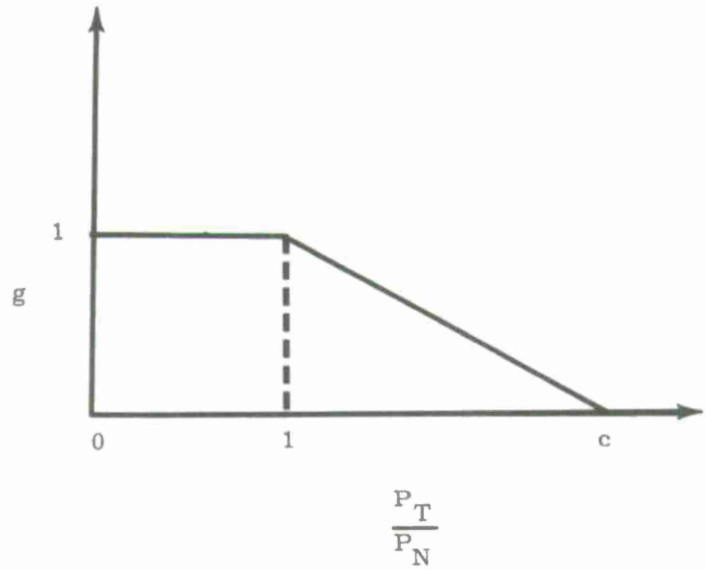


Figure 2-4. Overexertion function.

The last term of the PCC(M) equation is a function of the fatigue factor, as previously defined, which is dependent only upon time elapsed since last sleep and sleep duration.

The group physical capability is calculated as the average of the physical capability values over all group members.

Competence

Job competence, as employed in this simulation model, represents those aptitude, ability, training, and experiential factors which determine how well an individual performs on the job. It pertains to the quality, or accuracy, of performance, and is almost completely independent of the speed of performance. The overall influence of this variable is for greater competence to yield more accurate task performance. The only circumstance in which competence bears any relationship to event completion time in the model is in the circumstance of an event which must be repeated if performed unsatisfactorily. The less competent individual has a lower probability of succeeding on an event. Since repetitions consume time, satisfactory completion of that event will take the less competent operator longer than his more competent peer--not because he necessarily works more slowly--but because he is more likely to need to repeat the event.

Each simulated crew member is considered to have a degree of competence rated on a scale between zero and unity, in both a primary occupational specialty and a secondary specialty. Competence values at the start of a mission are selected by the computer on the basis of personnel input data. Mean and standard deviation values for the generation of such data are available in a number of sources.

Within the model, competence is one of the principal determinants of how well an event will be performed. Thus, as the competence of the persons selected to perform an event increases, the likelihood that they will perform the event satisfactorily also increases.

However, we do not assume competence to be static. Within the model, provision is made to allow competence to be modified as a function of experience (Ghiselli & Brown, 1948) and as the aspiration level varies. In the prior regard, Deutsch (1954, p. 208) maintained that "If an individual has considerable experience in a given activity, he will know pretty well what level he can expect to reach and the gradient of values on the subjective probability scale will be steep" and in the latter regard, Krech and Crutchfield (p. 410) contended that "A successful individual typically sets his next goal somewhat, but not too much, above his last achievement." Consequently, the model provides for increments in the competence of crew members during the mission simulation as a function of performance and aspiration levels. This relationship is shown in the first box of flow logic sheet 19 and is explained in a subsequent section of this chapter which is side headed "competence upgrading."

Stress

Provision is made within the model to simulate the effects of certain manifestations of anxiety and stress. Specifically, differences in the stress tolerance of individuals are simulated, as are individual anxiety levels and ractions to anxiety/stress.

Stress is operationally defined as the ratio of the amount of time needed for completion of the current event to the amount of time available for completing the event. This value is calculated for each event (i. e., for each group performing the event) during the simulated mission. Stress tolerance is simulated as a threshold, STRM(M), assigned for each crew member, against which the stress value is compared in order to determine program actions. Stress values which are below threshold are considered mild; those of threshold level and larger are considered severe. The general principle implemented is for mild stress to be psychologically organizing or facilitating, while severe stress is disorganizing or debilitating. This representation is consistent with the current literature on the influence of stress on various aspects of behavior. A number of others (e. g., Harris, Mackie, & Wilson, 1956; Torrance, 1961; and Hare, 1962) have reviewed the effects of stress on task performance. All of these essentially concur that stress exerts a beneficial effect up to a particular point, but beyond that point, stress is disorganizing.

Under severe stress, performance accuracy is expected to deteriorate. The incidence of careless errors with mounting pressure and with attempts to save time is a common observation. It is confirmed in most contemporary psychological views of anxiety influences. Accordingly, when an operator's current stress reaches the level of his stress threshold, the probability of successful task performance is reduced or, phrased alternatively, the probability of error is increased. When stress subsides to more modest levels (below the threshold), this effect is reversed.

As described above, stress also affects the operator's level of aspiration. So long as stress remains low relative to the stress threshold, aspirations, when attained, are reset higher. When stress mounts to the level of the stress threshold, if the aspiration level is not attained, it is reduced to the level of current performance. This influence of stress on the level of aspiration is an implementation of Lewinian psychology. In 1942, Lewin wrote that "A successful individual typically sets his next goal... above his last achievement.... The unsuccessful individual, on the other hand... becomes intimidated and gives up reaching out toward higher goals..." The model utilizes stress as well as performance records in differentiating the successful from the unsuccessful individual, in order to effect its program actions.

Finally, situational events can influence stress loads. In particular, emergency situations impose considerable stress upon all who are party to them. This very obvious effect is simulated by providing for the possibility of increased stress when certain selected emergencies occur.

In summary, the concept of a stress threshold, as defined for an individual in the prior model, developed by Applied Psychological Services for the Office of Naval Research (Siegel & Wolf, 1969), is extended in the present case to apply to the group. A group stress threshold, GSTRM, is calculated as the average of the stress threshold values of the men assigned to the group. The psychological stress of the group itself in accomplishing the event is now determined.

Psychological stress is a time-induced function dependent on the time available to the operator and his expected performance time. In the present model, therefore, if no event time limit, TL(IE), is specified as input data, the no stress condition, GSTR = 1.0, applies. If a time limit is specified, then the group stress is calculated as:

$$\text{GSTR} = \frac{\text{Expected Performance Time}}{\text{Time Available}} \times \text{Mental Load Factor}$$

where GSTR is limited between 1 and 5, the expected performance time is ADUR(IE), the time available is the time limit less start time = TL(IE)-Z2, and the mental load factor is 0.875 + LODM(IE)(0.25). This mental load effect is represented graphically in Figure 2-5. Here, LODM(IE) is the mental load input code.

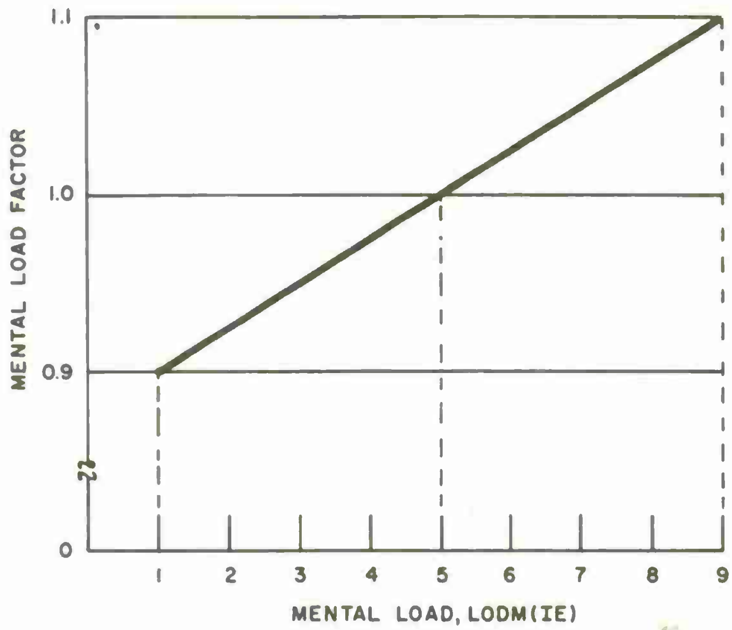


Figure 2-5. Mental load effect.

Event Duration

The next major segment of the processing, which represents, in a sense, the kernel of the simulation, is the calculation of the duration of the event. It involves variables such as stress, goal aspiration, pace, and group performance.

If the event is known to be of fixed duration, ASD(IE) = 0, or if the end time of the event is fixed, i. e., if event input specifies KE(IE) = 1, then it is not necessary to calculate the performance time and those variables upon which it is otherwise dependent. In such cases, the processing continues with circle g after the setting of the performance time, PT(IE), and event end time, ZC(IE). In preparation for this, the calculation of group performance (event success percentage) and group aspiration are accomplished next as the averages of the group members' individual values for these respectively.

PERF(M) = Current Performance of Each Man

$$= \frac{\text{Number of Successful Events Worked On Whole Mission}}{\text{Total Number of Events Worked On Whole Mission}}$$

GPERF = Group Performance = Average of Performance of the Men in Group

GASP = Group Aspiration = Average of Current Aspiration of the Men in Group

Aspiration

Provision is made to simulate the level of aspiration, or motivation, of each member of the crew. This is done by initially assigning individual aspiration values on a zero to one scale, permitting those values to affect the speed of performance, and then adjusting the aspiration values as a function of operator success records and the amount of stress being incurred.

The initial aspiration level represents the performance that the operator would hope to attain--the ratio of the number of event successes to the number of attempts. Thus, an operator with an aspiration value of 1.00 would aspire to succeed in every one of his task attempts, while an operator with aspiration value of 0.50 would have lower motivation and would be viewed as considering a rate of one successful attempt in two as acceptable.

As simulated, the level of a man's aspiration influences his working pace and stress, and is in turn subject to the influence of the degree of stress the operator is incurring and his success record. Considered are: (a) the operator's goal discrepancy--the difference between the aspired success record and the actual record, and (b) the difference between current stress on the operator and the operator's stress threshold. Comparison of the goal discrepancy with the stress differential provides the basis for the reciprocal influences involving level of aspiration. Five discrete circumstances can exist.

Case 0 No significant goal discrepancy

Case 1 Positive goal discrepancy (i.e., aspiration in excess of actual performance record) and subliminal stress

Case 2 Zero or negative goal discrepancy and subliminal stress

Case 3 Positive goal discrepancy and stress equal to or greater than threshold

Case 4 Zero or negative goal discrepancy and stress equal to or greater than threshold

Through the five cases described above, the level of aspiration variable, a motivational variable, can be seen to influence working pace and current stress, while being, in turn, influenced as a function of task success records and level of stress. The reciprocal and dynamic quality of the variable as treated in the model is quite consistent with aspiration level dynamics as described by such writers as Lewin (1942) and Kelley and Thibaut (1954).

The model's logic for processing each case is shown in Table 2-2 below.

Table 2-2

Goal Aspiration Cases

Case	Aspiration-Performance Condition	Stress vs. Threshold Condition	Result
0	$\lvert GASP-GPERF \rvert < 0.02$	-	None
1	GPERF < GASP	GSTR < GSTRM	Calculate pact adjustment factor
2	GPERF ≥ GASP	GSTR < GSTRM	Reduce aspiration level
3	GPERF < GASP	GSTR ≥ GSTRM	Set aspiration = performance Calculate pace adjustment factor
4	GPERF ≥ GASP	GSTR ≥ GSTRM	Reduce group stress

The pace adjustment factor is calculated as:

Case 1: PAF = 1.0 - 0.4 (GASP - GPERF)

Case 2: PAF = 1.0 + 0.4 (GASP - GPERF)

The pace adjustment effect is shown graphically in Figure 2-6. Thus, changes in the pace due to this adjustment factor are a linear function of the difference between aspiration and actual performance, where lower pace values indicate faster operators.

Case 1 presents a circumstance which will be recognized as predisposing positive motivational value--the operator is not performing as well as he would like to, yet he is only mildly stressed, if at all. The psychological expectation is that he would strive to perform better, and the model effects this by reducing his pace value, thus simulating his working faster.

Case 2 further illustrates the dynamic aspect of level of aspiration, both as occurring in life and as simulated in the model. Presented is a zero or negative goal discrepancy, which means that performance has at least equalled operator aspiration, and stress is still of only modest magnitude. Psychological theory (e. g., Deutsch, 1954) indicates that under these conditions, the operator would "raise his sights" and aspire to do more, since he demonstrated to himself that he has easily attained the initial level. In this regard, Krech and Crutchfield (1948) wrote:

> ...a successful individual typically sets his next goal somewhat, but not too much, above his last achievement. In this way he steadily raises his level of aspiration. Although in the long run he is guided by his ideal goal,..., nevertheless his real goal...is kept realistically close to his present position.

This process is simulated in the model according to a Monte Carlo procedure, as described in the next chapter.

Case 3 presents a circumstance of resignation. The operator is not performing as well as he would like, but is incurring severe stress. Because of the severe stress, he has no choice but to accept his current performance level. The model effects this by reducing the aspiration value so that it equals the performance record. The simulated operator has ceased his upward striving and avoids the severe stress by accepting his current performance. However, associated with the cessation of upward striving, with the "edge" off the individual's motivation, one might expect to observe the beginnings of a partly voluntary and partly involuntary deterioration in performance. This effect is simulated in the model by also increasing the pace value, thus slowing down the rate at which the operator performs his tasks.

In case 4, current stress is altered. Specifically, Case 4 presents the circumstance of performing equalling or exceeding operator aspiration, but stress being substantial. That is, the operator is incurring severe stress, despite the fact that he has attained the level of performance he set for himself. It seems reasonable that as he reviews his success record, he stops "sweating it" quite so desperately, for he has demonstrated that he can attain his aspiration level. In the model, this is simulated by reducing the operator's current stress by ten per cent.

In case 2, the increase in aspiration level is randomized to be equiprobable between a zero and 10 per cent increase. In case 4, the group stress reduction is always a 10 per cent reduction.

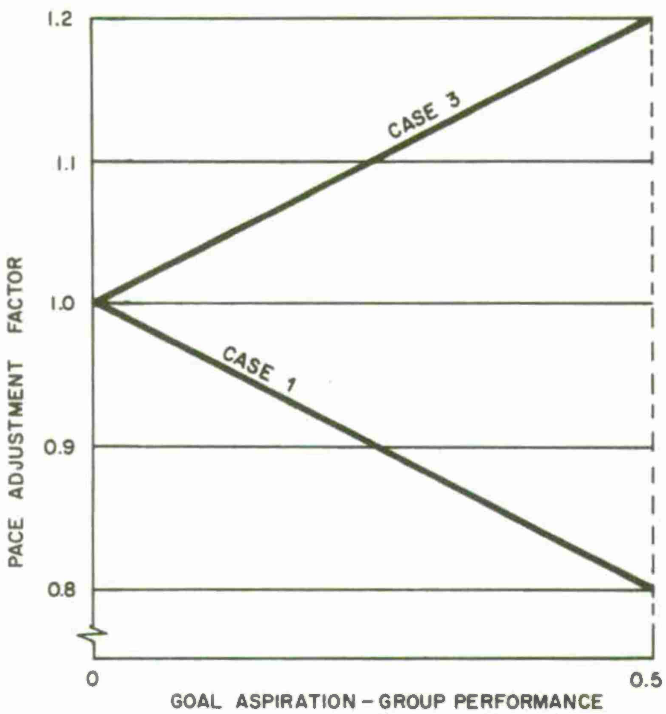


Figure 2-6. Pace adjustment effect.

Working Pace

The ISM model simulates differences in the pace, or the speed, at which each of the various crew members works. This variable is intended to summarize and represent individual differences which determine how quickly an individual performs a job. Speed of event performance is treated in the model independently from the accuracy of performance. The pace variable is one of the means by which the speed of performance is simulated.

Each member of the simulated crew is initially assigned a value to represent his normal working pace, PACE(M). The assignment is made by the computer, through random draw from a normal distribution of values with a mean equal to the input parameter Average Crew Pace, ACP, and standard deviation of 0.11. The concepts reflected in this distribution are establishment of unity as the "normal working pace" in the general population, and expressing variations from the norm in such a way as to satisfy a 2:1 ratio between the characteristic paces of the slowest operator and the fastest. From the distribution described above, an extremely slow worker would be represented by a value in the realm of three standard deviations above the mean, or PACE(M) = 1.33, an extremely rapid worker by a value in the realm of three standard deviations below the mean, or PACE(M) = 0.67, a very close approximation to 2:1. Such a range of differences, although seemingly large, is consistent with fairly fundamental psychological observations; for example, "Wechsler shows that the range of most physical and mental activities vary as 2 to 1...[Barnes, 1954, p. 353, in reference to one of David Wechsler's (1935) early works]."

A value for the pace of the group on each variable time event (GPACE) is calculated as the average of the pace values for the men in the group. The purpose of the pace variable then is to influence the time worked by a group on each simulated variable time event. Ignoring other factors for the moment, it is desired that a slower group (say one with a group pace value 1.1) would take ten per cent longer than nominal and a faster group, with pace value of 0.75, would perform the task in three-fourths of its nominal execution time, plus or minus the stochastic effect. Thus, the group pace value functions in the model as a multiplicative modifier of the execution time assigned.

Fatigue affects the speed of task performance as well as the quality of performance (Ghiselli & Brown, 1955, p. 249). Its influence on quality has been described and its influence on speed is represented in a very similar way. The reader will recall that fatigue builds as a function of the amount of time since the operator last slept, and as a function of tasks performed in that interval. After each event, a current fatigue level is calculated and, via the physical capability variable, is employed to alter the operator's existing pace value. The nature of the alteration is to increase pace values with the buildup of fatigue (decrease in physical capability), thus rendering more slow the execution time for subsequent work as the operator becomes more tired.

Group Pace Calculations

In the simulation, the work speed of the group for an event, termed its pace, is determined as the product of three factors. The primary influence is the average of the individual pace values, PACE(M), of the men assigned to the event. The second is the pace adjustment factor just discussed and shown in Figure 2-6. The third, called the slowness factor, SF, is dependent on the value of physical capability, PCC(M), of each group member, as shown in Figure 2-7. This figure indicates no effect on operator speed for an average, PCC(M) = 1 value, but that operator speed is halved when physical capability is completely degraded and doubled when PCC(M) reaches a maximum limit value of 2. Thus, fatigue, sleep, and overexertion elements enter the pace computation which, in turn, influences performance time.

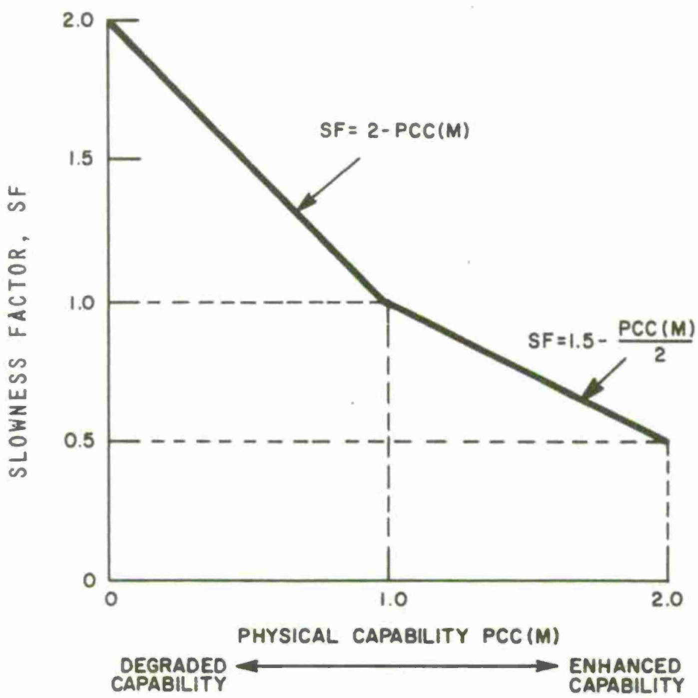


Figure 2-7. Determination of slowness factor.

Event Performance Time

Three factors comprise the performance time, PT(IE), calculation for scheduled events. The first is a value, V, selected from the normal distribution with mean, ADUR(IE), and standard deviation, ASD(IE), both given as input. The second factor is ZIJ. The group stress and group stress threshold influence the ZIJ value and thence performance time, as shown in Figure 2-8.

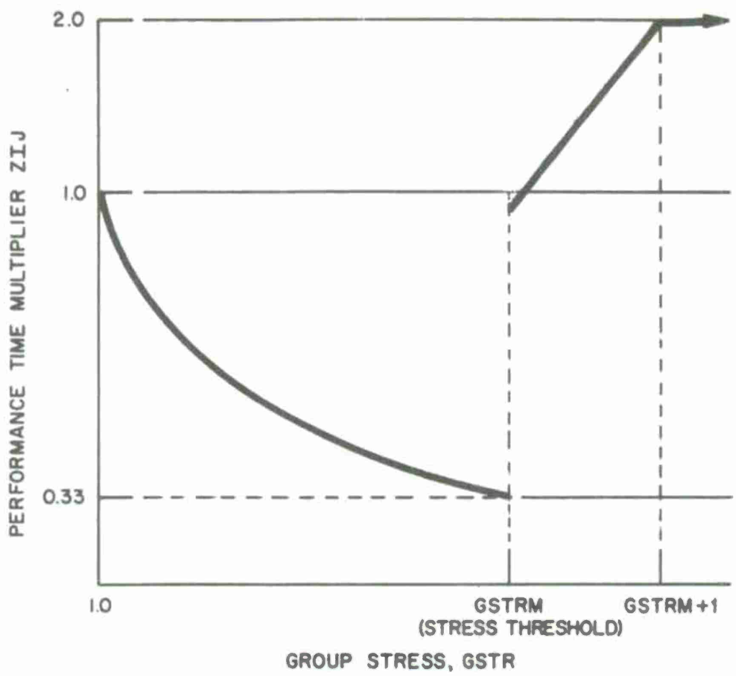


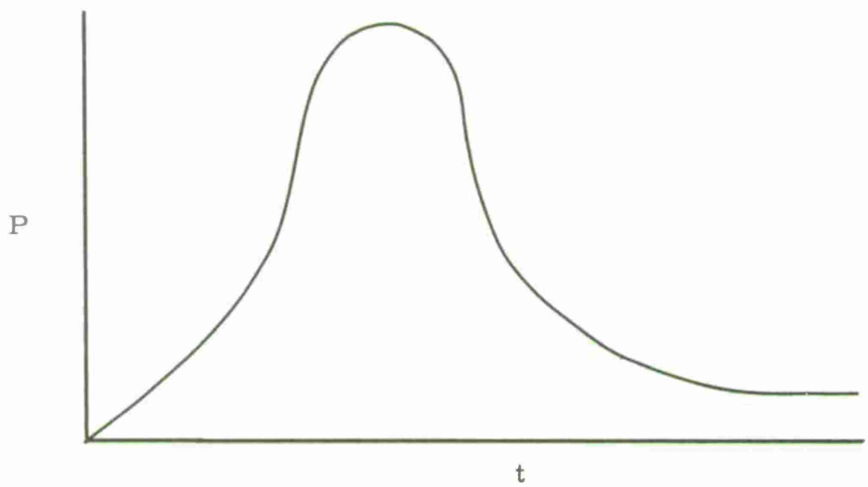
Figure 2-8. Stress effect.

The result is a value, ZIJ, which is a multiplicative factor for V in the determination of performance time. The third factor entering this calculation is the group pace value, GPACE, just discussed. Thus, performance time is calculated as:

$$
PT(IE) = \begin{cases} (V)(ZIJ)(GPACE) & \text{if } GSTR \le GSTRM \\ GPACE\,[V(2GSTR-GSTRM+1 - ADUR(IE)\cdot(GSTR-GSTRM)] & \text{if } GSTRM \le GSTR \le GSTRM + 1 \\ GPACE\,[3V - ADUR(IE)] & \text{if } GSTR > GSTRM + 1 \end{cases}
$$

and is limited to lie between 0 and 4 ADUR(IE).

A modified calculation for V is employed for repair events. In studies which pay particular attention to repair time, it is conventional to assume a logarithmic normal distribution. This gives a probability density function that rises steeply for small values and is less accentuated for large values as shown below:



Then, ln t is normally distributed. The difference from normal distribution is that the program generates a random value of ln t from a normal distribution and then the exponential of this value of ln t is the random value of t.

The following describes the computation involved in choosing appropriate values of mean and standard deviation. If $y = \ln x$ is normally distributed with a mean μ and standard deviation σ, then x will have mean ζ

$$\zeta = e^{\mu + \sigma^2/2}$$

and variance:

$$\sigma_x^2 = \zeta^2 \left(e^{\sigma^2} - 1\right)$$

i. e. ,

μ = mean of logarithm of repair time

ADUR(IETY) = ζ = mean of repair time

TEM 3 = σ = standard deviation of logarithm of repair time

ASD(IETY) = σ_x = standard deviation of repair time

Solving the above equations for μ and σ by algebraic step we determine:

$$\text{TEM 1} = e^{\sigma^2} = 1 + \frac{\sigma_x^2}{\zeta^2}$$

and determine μ by:

$$\text{TEM 2} = e^{\mu} = \frac{\zeta}{\left(e^{\sigma^2}\right)^{\frac{1}{2}}}$$

Then μ and σ are used with normal random deviate intrinsic function, and exponential of this result is the random repair time.

In FORTRAN notation:

$$\text{TEM 1} = 1 + \frac{[\text{ASD(IETY)}]^2}{[\text{ADUR(IETY)}]^2}$$

$$\text{TEM 2} = \frac{\text{ADUR(IETY)}}{\sqrt{\text{TEM 1}}} = \frac{\zeta}{\sqrt{\text{TEM 1}}}$$

$$\text{TEM 3} = \sqrt{\ln \text{TEM 1}} = \sigma$$

Then:

$$V = e^{(\ln \text{TEM 2} + \text{RD} \sqrt{\ln \text{TEM 1}})}$$

which is used only for repair events.

Following determination of event performance time, the time of day at which the event was completed, ZC(IE), is calculated as event start time plus performance time = Z2 + PT(IE). If completion time is later (larger) than the time limit for the event, TL(IE), given as input, then the event is assumed to last only until TL(IE), i. e., ZC(IE) = TL(IE) and PT(IE) = TL(IE) - Z2(IE). The balance of the unworked time is tallied as unmanned station hours, USH.

If the event time exceeds 24, then PT = 24 - Z2 so that no events will carry over to the next day. In this case, ZC = 24.

Event Bookkeeping

Beginning with circle g in the flow chart, a variety of additional event bookkeeping calculations are completed based upon availability of the value of performance time.

First, for each equipment used in the event the cumulative equipment up time and down time (for the current day) are revised. For scheduled and emergency events (in which equipment is assumed operational) up time for each equipment is simply:

$$CUT(IQ) = CUT(IQ) + PT(IE)$$

For each repair event, the duration of which is assumed to represent an equipment inoperability period, cumulative equipment down time is :

$$CDT(IQ) = CDT(IQ) + PT(IE)$$

A sum of actual repair times (event times for repair events) is maintained for each equipment as:

$$CART(IQ) = CART(IQ) + ADUR(IE)$$

Next, performance level, the equivalent of MTBF, is calculated for each equipment as:

$$EPL(IQ) = \frac{CUT(IQ)}{CUT(IQ) + CDT(IQ)}$$

The time since last sleep, HSLS(M), is augmented for each working group member by adding the performance time for the event. Then the tally of time worked for the day, for each group member, TW(M), is revised, and the last time of day worked, Z(M), is set, for each group member, equal to the event completion time, ZC(IE). Then the number of calories expended on this event by each man, CCAL(M), is calculated to be equiprobable between 0.95 and 1.05 times the product of IEC(IE, NT) and PT(IE). Next, the total number of calories expended since last sleep, ACAL(M), is adjusted by adding a current event calorie value, CCAL(M). The CCAL(M) value is also used in accumulating the tally of calories expended by each group member for the current day, IDC(M).

Next, the crew mental load is cumulated in load-time units. Given the mental load code, LODM(IE), which specifies the graduated load scale and which applies during the period of event performance, PT(IE), the value $LODM(IE) \cdot PT(IE)$, is added to prior values to summarize current crew mental load units.

Similarly, the event hazard class code IH(IE) is multiplied by PT(IE) to provide a measure of hazard units, EH, accumulated as TEH for later calculation of the safety index on a daily basis.

Performance Adequacy

Having determined the values for all of the variables affecting the performance of the event, the adequacy of the performance may now be determined. The following four variables are considered for each man in the group associated with the performance of the event:

Variable	Range of Values
stress	1-5
competence	0-1
physical capability	0-2
aspiration	0-1

With each of these variables, the model associates a function for the work group which varies from 0-1, in which unity represents perfection. These four functions are then combined to obtain an overall measure of how well the group performed. The function for effectivity (goodness) of stress is given below and shown in Figure 2-9.

$$ES = \begin{cases} \dfrac{(1-BE)GSTR}{GSTRM-1.0} + BE & \text{if } GSTR < GSTRM \\[2ex] \dfrac{5-GSTR}{5-GSTRM} & \text{if } GSTRM \le GSTR \le 5 \\[2ex] 0 & \text{if } GSTR > 5 \end{cases}$$

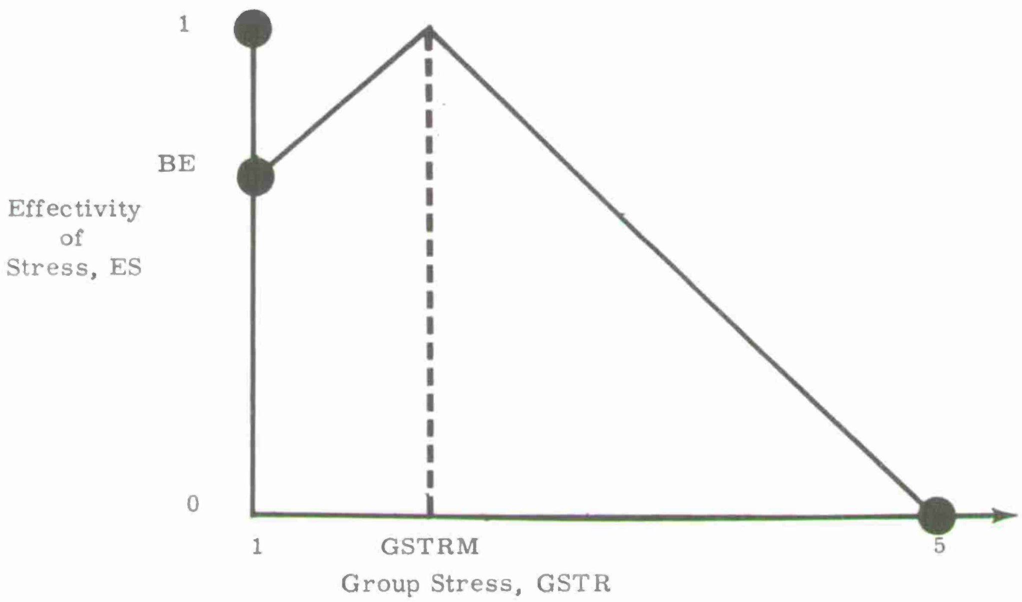


Figure 2-9. Stress effectivity.

The effectivity function for competence, EC, utilizes the values of crew member competence, TPCOM(M), previously degraded as a function of sea state and provides for added weight to be given to the competence of the leader, TPCOM(LI), as shown below:

$$EC = \frac{\{2[TPCOM(LI)] + \Sigma TPCOM(M)\}}{IG + 2}$$

Here, the summation is taken over all members of the group. This represents an average competence value for the group in which the leader's competence has been given two extra weighted shares. In the determination, TPCOM(M) is selected as either the competence in the primary specialty, TPCOM(M), or in the secondary competence, TSCOM(M), depending upon the actual assignment of the men during the event.

In the situation of a repeat (second try) of an event due to failure to perform satisfactorily the first time, 0.2 is added to EC on the repeat to simulate a short term increase in the effectivity for group competence. This increase is justified since the group has worked recently together and has had the benefit of immediate experience.

The effectivity for the physical capability, EF, is set equal to the group physical capability value itself, GPCC, if less than one, and is set equal to unity if GPSS exceeds unity.

The fourth and last function is the effectivity of aspiration, EA. It is treated like competence, with the leadership aspiration receiving extra weight, as follows:

$$EA = \frac{\{2[CASP(LI)] + \Sigma CASP(M)\}}{IG + 2}$$

In order to calculate from these four measures a single value for performance adequacy, the following formula is used:

$$PA = \sqrt{\frac{3(ES)(EC) + (ES)(EF) + (ES)(EA) + 3(EC)(EF) + 3(EC)(EA) + (EF)(EA)}{12}}$$

which simplifies to:

$$PA = \sqrt{\frac{3(EC)(ES + EF + EA) + ES(EF + EA) + (EF)(EA)}{12}}$$

A potential degration in this value of PA is taken into consideration if the current event is either a repair or emergency. If such is the case and if the computed duration of the event, PT(IE), exceeds the maximum (target) duration of that event which is provided as an input, then PA is degraded by the ratio of DTR(IQ)/PT(IE) for repair events or DTE(K)/PT(IE) for emergencies.

Event Performance Efficiency

For later use in determining mission performance efficiency, a running sum is maintained of performance efficiency values for each event.

$$\text{Efficiency} = \frac{\text{event essentiality x performance adequacy}}{\text{performance acceptability level}}$$

This efficiency function is calculated for each event. It is, essentially, a ratio of actual event results (performance adequacy weighted by event essentiality) to the level of performance acceptable to the supervisor. The cumulative sum of event performance efficiencies, SEF, is calculated as a function of the performance adequacy, the event importance (essentiality value), IESS(IE), the leader's aspiration, CASP(LI), and the constant, K7, which indicates the level of acceptable performance, described below, as follows:

$$SEF = SEF + \frac{PA \cdot IESS(IE)}{CASP(LI) \cdot K7}$$

Also, a similar running sum of event essentiality values, ISIE, is maintained for the day.

Recalculation of PCC(M) and FAT(M)

The values of physical capability and time fatigue are now adjusted in the same manner as was described previously for each group member who participated in the event simulated. The prior calculation is required only if there was a time interval between the prior event and the current event. However, the calculation is not required in every case. It represents an updating of values as a result of time worked on the current event, TW(IE), and the new values represent the situation at the end of the current event. The fatigue, FAT(M), the physical capability of each man in the group, PCC(M), and the group physical capability, GPCC, are calculated as previously described.

Adjustment of Consumables

The revised level of consumables available is determined next. First, the actual amount of consumables expended is calculated either as a function of event performance time and expenditure rate or on a unit expenditures basis. Then prior values of the L consumables, KON(L), are adjusted to account for consumption during the event.

Since the rate of expenditures for some events is more logically given in terms of usage units per event rather than per hour, the logic of the model considers both types of expenditures independently. Accordingly, for "unit" events the current level of expenditures, KONC1(L1) is:

$$KONC1(L1) = KONC1(L1) - IRC1(L1)$$

where IRC(L1) is the number of units expended per event.

For events in which expenditures are accounted in terms of units per hour, the corresponding effect is accomplished by multiplying the rate of expenditure of each consumable by the duration of the event and cumulatively subtracting the product from current values for each consumable:

$$KONC(L) = KONC(L) - IRC(L, IET) \cdot PT(IE)$$

Event Success or Failure Determination

Performance adequacy, just calculated, is an important element in determining the success or failure of the performance of an event. An initial estimate of a criteria for success might be whenever performance equals or exceeds the leader's expectation, i. e., when PA > CASP(LI). However, it must be conceded that a team's leader will be willing to accept "something less" than his own performance aspiration value as constituting acceptable performance for a group of his peers or subordinates. Thus, the model uses the constant K7 for this "something less" and defines an event to be successful whenever:

$$PA > [CASP(LI)]K7.$$

Performance Level

After determining performance adequacy, the model increases by one the tally of the number of successes or failures, as appropriate for each man who worked on the event. These tallies are NOSUC(M) and NOFAIL(M) and are accumulated over the entire mission iteration. A new performance value, PERF(M), for each man who worked on the event is now determined as the ratio of the number of successes to all events in which he has participated.

Event Results Recording

Next, the results of a single completed event are optionally recorded for later printing. If the option to record detailed event results is taken (print option 5, IND(5) = 1), the results are recorded and printed for analysis. Included in the printout are the following results for each event: successful/unsuccessful, men available, start time allowed, prior event requirements time finished, event start time, event duration, event end time, unmanned hours, group stress, physical capability, pace, aspiration, performance adequacy, hazard, consumables used and remaining, men on the job, and each man's fatigue, physical capacity, hours worked (cumulative), calories expended on this task, calories expended (cumulative) hours since sleep, idle hours, hours slept, cumulative performance, and aspiration, as shown in Figure 2-10.

The printout for each event performed is concluded with data on each man who was assigned to the event. Here, an asterisk in the LDR column identifies the work group leader.

Failure Processing

In the case of an event which is unsatisfactorily performed, the repeat-touch-up code, R/TU(IE), of the input data determines whether the entire event is to be resimulated (repeated) or whether it is to be partially redone (touched up). If the event is coded as 1 (repeat), a second try is accomplished by returning to circle g in the processing flow chart. Only one such repetition is allowed for any event occurrence. If the second attempt is also unsatisfactory, the processing continues at circle h.

If the event is coded as 2 (touchup), a second try is simulated during which the performance time is set equal to one-half of the value of the performance time previously calculated. Again, second try processing begins at circle g.

If the failure processing code is a 3 (no repetition permitted), the processing continues at circle h, and the processing is the same as that which takes place after a task repetition or touchup.

End-of-Day Processing

Then, at circle h of the model flow chart, a check is made to determine whether or not the current event being simulated represents the last event of the day. If the event which has just been simulated is not the last event of the day, then the next event is selected as a function of the pointer and the probability of each of the three alternative paths, PRB(IE, IA), given as input data. The processing returns to circle d to begin the simulation of the next event in turn.

```
APPLIED PSYCHOLOGICAL SERVICES--NAVSEA HURT AIS,MRL,JJW,JB                    11/05/74            PAGE   18

EMERGENCY EVENT      3  DAY  1  ITERATION  1        S
MEN AVAIL 16.0  START ALLOWED  0.   PRIOR EVENT  0 FINISHED  0.   EVENT STARTS 16.00 LASTS  0.49 ENDS 16.49 UNMANNED HRS    0.
GROUP STRESS 2.26 PHYS CAP 1.01 PACE 1.0  ASP 0.85 PERF AD  1.03 HAZ  0.5
PER HR CONS USED=    0,     0,     0,     0,     1,     1,     1,     1,     1,     1,
PER HR CONS LEFT=15124, 9974, 5974, 4974,   474,   474,   474,   474,   474,   474,
UNIT CONS USED=    5      5      5      5      5      5      5      5      5      5
UNIT CONS LEFT=  462    472     72     72     72     62     72     72     72     72

MAN TYPE  SPEC   LDR RANK FATIGUE PHYS CAP HRS WRKD CALORIES CALS*HRS SINCE SLEEP IDLE HRS SLEPT CUM PERF  ASP
  2    1    P     *    1   0.883    1.001     6.40     74.4    1430.9        17.4  0.          0.      0.82 0.82
  8    9    P          4   0.820    1.019     6.46    105.0    1525.7        17.2  7.7         0.      0.89 0.89

SCHEDULED EVENT      7  DAY  1  ITERATION  1        S
MEN AVAIL 16.5  START ALLOWED  6.0  PRIOR EVENT  0 FINISHED  0.   EVENT STARTS 16.49 LASTS  4.11 ENDS 20.60 UNMANNED HRS   31.93
GROUP STRESS 1.12 PHYS CAP 0.89 PACE 1.2  ASP 0.85 PERF AD  0.95 HAZ  4.1
PER HR CONS USED=    4,     4,     4,     4,     4,     4,     4,     4,     4,     4,
PER HR CONS LEFT=15120, 9970, 5970, 4970,   470,   470,   470,   470,   470,   470,
UNIT CONS USED=    1      1      1      1      1      1      1      1      1      1
UNIT CONS LEFT=  461    471     71     71     71     61     71     71     71     71

MAN TYPE  SPEC   LDR RANK FATIGUE PHYS CAP HRS WRKD CALORIES CALS*HRS SINCE SLEEP IDLE HRS SLEPT CUM PERF  ASP
  3    3    P     *    2   0.848    0.806    10.02    915.3    2188.8        21.9  0.5         0.      0.80 0.80
  8    9    P          4   0.820    0.977    10.57   1611.2    3136.9        21.3  0.          0.      0.89 0.89

SCHEDULED EVENT      8  DAY  1  ITERATION  1 IS IGNORED DUE TO  NULL GROUP

SCHEDULED EVENT      9  DAY  1  ITERATION  1 IS IGNORED DUE TO  NULL GROUP

SCHEDULED EVENT     10  DAY  1  ITERATION  1 IS IGNORED DUE TO  LOW ESSENTIALITY OF  0

REPAIR FAMILY        1  DAY  1  ITERATION  1        U
MEN AVAIL 23.7  START ALLOWED  0.   PRIOR EVENT  0 FINISHED  0.   EVENT STARTS 23.67 LASTS  0.02 ENDS 23.69 UNMANNED HRS    0.
GROUP STRESS 1.65 PHYS CAP 0.90 PACE 0.7  ASP 0.92 PERF AD  0.98 HAZ  0.1
PER HR CONS USED=    0,     0,     0,     0,     0,     0,     0,     0,     0,     0,
PER HR CONS LEFT=15126, 9976, 5976, 4976,   476,   476,   476,   476,   476,   476,
UNIT CONS USED=    1      1      1      1      1      1      1      1      1      1
UNIT CONS LEFT=  479    479     79     79     79     79     79     79     79     79

MAN TYPE  SPEC   LDR RANK FATIGUE PHYS CAP HRS WRKD CALORIES CALS*HRS SINCE SLEEP IDLE HRS SLEPT CUM PERF  ASP
  5    6    P          3   0.848    0.919    18.13      6.6    4624.0        25.1  0.          0.      0.11 0.86
  7    8    P     *    3   0.872    0.890    11.69      6.3    3759.8        24.8  0.          0.      0.07 0.98

REPAIR FAMILY        1  DAY  1  ITERATION  1        S
MEN AVAIL 23.7  START ALLOWED  0.   PRIOR EVENT  0 FINISHED  0.   EVENT STARTS 23.69 LASTS  0.31 ENDS 24.00 UNMANNED HRS    1.78
GROUP STRESS 3.18 PHYS CAP 0.89 PACE 1.5  ASP 0.92 PERF AD  0.65 HAZ  0.9
PER HR CONS USED=    0,     0,     0,     0,     0,     0,     0,     0,     0,     0,
PER HR CONS LEFT=15126, 9976, 5976, 4976,   476,   476,   476,   476,   476,   476,
UNIT CONS USED=    1      1      1      1      1      1      1      1      1      1
UNIT CONS LEFT=  478    478     78     78     78     78     78     78     78     78

MAN TYPE  SPEC   LDR RANK FATIGUE PHYS CAP HRS WRKD CALORIES CALS*HRS SINCE SLEEP IDLE HRS SLEPT CUM PERF  ASP
  5    6    P          3   0.842    0.914    18.44    122.4    4746.4        25.4  0.          0.      0.16 0.11
  7    8    P     *    3   0.968    0.875    12.00    116.2    3876.0        25.1  0.          0.      0.13 0.07

REPAIR FAMILY        1  DAY  1  ITERATION  1 IS IGNORED DUE TO  NO TIME AVAILABLE
```

Figure 2-10. sample event output.

If the event just simulated is, in fact, the last one of the day, then the computations continue with the determination and summarization of several end-of-day conditions. These are:

average physical workload	APW(M)	each man
primary competence	PCOM(M)	each man
current crew competence	CCC	crew
physical incapacity	PI	each man
safety index	SI	crew
crew mental load	CML	crew
average equipment performance level	AEPL	crew
equipment performance efficiency	EPEFF	equipments
system performance efficiency	PEFF	system
system reliability level	SRL	system
system performance level	SPL	system
system global effectiveness measure	SGEM	system

Average Physical Workload

As a measure of under/over exertion for each man in the crew, the value of average physical workload, APW(M), is calculated. It is determined for each crew member as follows:

$$APW(M) = \frac{\text{calories expended during day's work}}{\text{calories per this man's average day}} \times \frac{\text{no. of hours worked}}{\text{no. of hours in average workday}}$$

$$= \frac{IDC(M)}{CAL(M)} \times \frac{TW(M)}{WORK\,1} \; .$$

This variable provides a measure of load on personnel, and in that regard may be partially redundant with the unadjusted number of hours worked each day.

Competence Upgrading

To implement crew learning in the course of a simulated mission, the logic calls for increases in primary competence on a daily basis for each crew member whose competence in his primary specialty is less than his current aspiration. The mission is assumed to be sufficiently short so that no degradation of competence occurs in an unused skill, and it is assumed that failure in performing an event does not degrade competence.

The competence upgrading scheme is based on the work of DeJong (1957) and of Crossman (1959). Of particular importance was the work of Blackman (1936) and Crossman (1956), which indicated that performance proficiency (here termed competence) on a given task (event) continued to increase even after 10, 000 "trials."

In updating TPCOM(M) at the end of each day for man M, the following formula was developed:

$$TPCOM(M) = PCOM(M) + [CASP(M) - TPCOM(M)]\,NU(M)[0.0017]$$

where NU(M) is the number of successful events participated in by man M on day ND. The constant, 0. 0017, was determined by the condition that in 30 days, PCOM(M) shall not increase by more than 0. 1 from an initial value of 0. 75, based upon 80 events per day for a given M with a maximum value of unity for CASP(M) representing optimum aspiration.

Table 2-3 gives results for PCOM(M) for the constant selected:

Table 2-3

Maximum TPCOM after Various Numbers of Days

Number of Days	PCOM(M)
0	. 7500
10	. 7892
20	. 8222
30	. 85005
50	. 89335
100	. 9545
200	. 9917

After a new value of primary competence that has been calculated for each man in the crew, a current crew competence, CCC, is determined as the average of the individual values.

End-of-Day Performance Measures

Table 2-4 presents a summary of the end-of-day measures calculated to summarize human, equipment and system performance.

Table 2-4

End-of-Day Performance Measures

Type of Measure	Variables Calculated and Their Frequency		
Human Reliability	Performance = PERF(M) (each man, each event)	System Reliability Level = SRL (each day)	Global System Effectiveness Measure = GEM (each day)
Equipment Reliability (availability)	Equipment Performance Level = EPL(IQ) (each equipment, each event)		
Human "Performance Adequacy"	Performance Adequacy = PA(IE) Performance Efficiency = PEFF (each event)	System Performance Level = SPL (each day)	
Equipment Performance Adequacy	Equipment Performance Efficiency = EPEFF (each event)		

To recognize the importance of equipment performance in the total mission effectiveness measures, two values are calculated at the end of each simulated mission day. This serves to quantify how well the ship's equipment performed during the day. The first such measure, the average equipment performance level, AEPL, is merely the average of EPL values taken over all equipments. The second is the equipment performance efficiency, EPEFF, calculated as AEPL times the ratio of the sum of average repair duration input data value, ADUR(IET), for the day's repair events to the sum of actual repair times for these same events. As such, it represents a measure of equipment performance based on simulated repairs each day.

Next, the human performance efficiency for the simulated day is calculated. It is the sum of three factors. The first and most basic is the ratio:

$$\frac{\text{sum of event performance efficiency values} = \text{SEF}}{\text{sum of event essentiality values} = \text{ISIE}}$$

This factor then measures the effect of performance adequacy, leader's aspiration, and K7 values over the events performed for the day. The second is a factor which measures degradation due to the total amount of unmanned station hours for the day normalized by dividing by the total number of crew working hours:

$$1 - \frac{\text{USHT}}{(\text{IC})(\text{WORK 1})}$$

The last factor is a degradation of human performance efficiency due to the extent to which events were ignored,

$$1 - \frac{\text{NIGR}}{\text{NTE}}$$

where NIGR is the number of events ignored and NTE is the total number of events simulated during the day.

In order to calculate system reliability level, SRL, combining both human and equipment reliability measures, the range of variation of each was normalized. Here, it was assumed that the average performance over all men in the crew would be in a range from 0.65 to 1.0, i.e.,

$$0.65 \leq X = \sum_{M=1}^{IC} \text{PERF}(M) < 1.0.$$

This range of values and the values for the equipment reliability range were selected initially on the basis of judgment as to anticipated results from the model. However, additional experience is required to confirm them and, therefore, they are subject to change. It is anticipated that such change will be implemented to allow a wider range for equipment (hardware) reliability. Then, a new value, $X' = X - 0.65/1-0.65$, was defined whose range, based on X, would be from 0 to 1. Similarly, on the basis of an estimation that the variable AEPL, average equipment performance level, would lie in the range from 0.9 to 1.0, i.e., $0.9 \leq Y = \text{AEPL} \leq 1.0$, a new variable $Y' = Y - 0.9/1 - 0.9$ was defined. This variable is based on Y, whose range would be the same as that of X'. What is desired is the combination of X and Y in such a way that the result, SRL, would be expected to lie in the selected range 0.7 to 1. A concave relationship was selected for the combination:

$$Z' = X' \cdot Y'$$

Then, converting Z' by linear scaling we have:

$$Z = 0.7 + Z'(1 - 0.7)$$

Thus, Z' will vary between 0 and 1 when Z varies between 0.7 and 1.0, and to obtain Z, we have:

$$Z = \text{SRL} = 0.7 + (X' \cdot Y')(1 - 0.7)$$

$$\text{SRL} = 0.7 + 8.571(X - 0.65)(Y - 0.9).$$

A corresponding treatment was given in the calculation of system performance level, SPL, from PEFF and EPEFF:

$$\text{SPL} = 0.7 + 8.571(\text{PEFF} - 0.65)(\text{EPEFF} - 0.9).$$

To combine SRL and SPL, each of which varies from 0.7 to 1.0, a convex treatment was selected. This combinatorial technique is also subject to revision. Here we let:

$$\text{SPL} = P' = \frac{P - 0.7}{1 - 0.7}$$

$$\text{SRL} = Q' = \frac{Q - 0.7}{1 - 0.7}$$

$$R' = \sqrt{\frac{(P')^2 + (Q')^2}{2}}$$

(It is noted that SPL and SRL are figures of merit or "scores" calculated on a known but arbitrary scale. They are not probabilities as such.)

Then, the combination of SRL and SPL, called general system measure, equals:

$$SGEM = R = 0.7 + R'(1 - 0.7)$$

$$= 0.7 + \sqrt{\frac{(SRL - 0.7)^2 + (SPL - 0.7)^2}{2}}$$

This measure, like SRL and SPL, is a "figure of merit" or "index of effectiveness" rather than a probability measure. Further work is anticipated relative to the refinement of a total effectiveness measure.

Physical Incapacity

Except on the last day of the mission, the calculation of physical capability is now performed again in the same way as described above under the heading "Crew Formation and Initial Value Selection." Here, again, at the end of each day of the mission (except the last), a determination is made regarding which crew members are to be simulated as degraded (sick) and, if so, how much, and for how many days. The only added processing required at the end of the day is the bookkeeping to reduce the duration of the incapacity, PI2(M), by one day for each man already incapacitated. If PI2(M)= 0, indicating that crew member M was not incapacitated in the preceding day, then PI(M) = 1.0. If PI2(M) ≥ 1, indicating the duration of the crew member's incapacitation, then PI2(M) is decreased by unity and his incapacity level is indicated by PI(M).

Safety Index

Another end-of-day processing calculation is the determination of a safety index, SI, for the crew. This index is formed as a function of the event hazard codes assigned to events performed during the day and of the length of time spent in each of these hazard classifications. A safety index of unity is optimum, that is, minimum hazard conditions possible; a safety index value of zero indicates the worst possible hazard conditions.

The event hazard values for all events of the day are cumulated and called total event hazard, TEH. This value is then divided by the total maximum possible value for the daily event hazard. The ratio is called the hazard ratio:

$$HR = \frac{\text{total event hazard for day}}{\text{maximum possible hazard for day}}$$

$$= \frac{TEH}{9(THW)}$$

where THW, the total hours worked, $= \sum_{M=1}^{IC} TW(M)$.

Having determined the hazard ratio, the computer then determines the safety index as follows:

$$SI = \frac{9}{8}(1 - HR).$$

This relationship is shown in Figure 2-11 and is based on the fact that event hazard assumes values from 1 to 9.

Thus, the index equals zero when all event time is spent in a maximum hazard condition and equals unity when all event time is spent under minimally hazardous conditions.

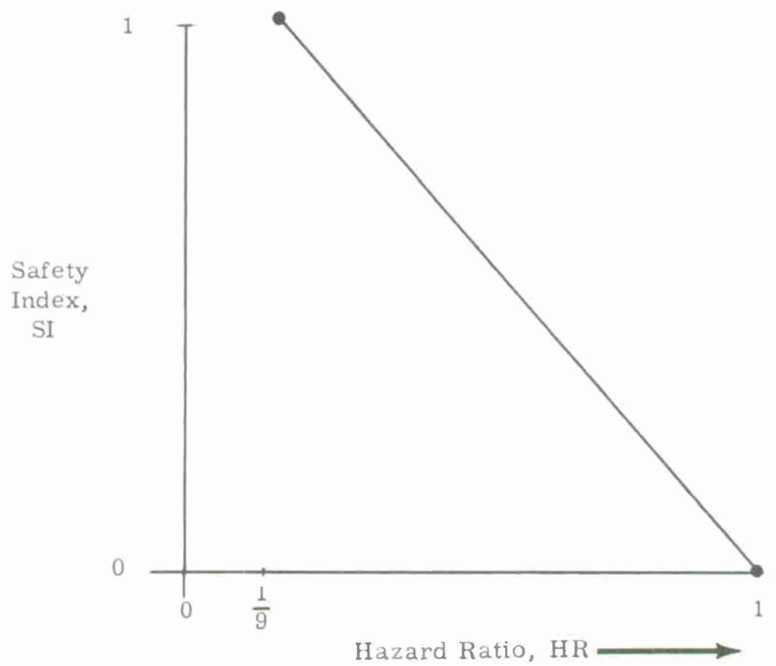


Figure 2-11. Safety index.

A revised scaling of crew mental load is accomplished so as to be consistent with 0 to 1 scaling used for the physical load variable:

$$\mathrm{CML} = \frac{\mathrm{CML}}{9(\mathrm{THW})}$$

End-of-Day Sleep

At the completion of the processing of all events for the day and various end-of-day calculations, the model determines the end-of-day sleep requirement and the corresponding fatigue level for each man. Prior to simulating each event, the model checks to determine if conditions permit the selected crew members to sleep between the current and their prior work event (these conditions are time available, catnap time threshold, and fatigue level threshold). Thus, the program provides for operators taking their sleep periods during the 24 hour days, as conditions permit.

Since conditions may permit additional sleep at the conclusion of all work for the day, the processing logic provides for determining the end-of-day sleep status for all crew members. This process determines how much sleep each man should have between the last time worked, Z(M), and the day's end, 24.0 hours. If the time available for sleep, 24-Z(M), exceeds the parameter CN + 0.5, and if the crew member has not had his full quota of sleep for the day, MAXSL, then a sleep period is simulated by calculating sleep duration (limited to MAXSL). As the result of this sleep, new values are generated for time fatigue (reduced due to sleep relief), hours since last sleep, HSLS(M), and a physical capability, PCC(M), all effective at the start of the next day.

End-of-Day Recording

The basic computations completed, processing now turns to reporting of results. If print Option 6 has been taken, the summarized results of the day just simulated are recorded for printout on the computer's high speed line printer. Figure 2-12 shows a sample tabulation. The first section provides summarized event and status information for the overall crew performance. Most of the headings shown are self explanatory. All times are given in hours. The AVG PERF ADEQ (average performance adequacy, third line) is a mean of the performance adequacy value of all events performed. The AVG FAIL DIFF (average failure difference) is a mean, taken only for failed events, indicating the difference between performance adequacy, (PA), and the required performance level, CASP(LI)·K7. The second section shows important data summarized by man. These results are either totals for all daily activity (hours worked, slept, idle, number of events successfully performed), or represent end-of-day conditions (fatigue, aspiration, competence). Averages for all of the elements in the second section follow the individual crew member summaries and represent daily summaries for simulated variables for the day.

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REPORT FOR DAY 1, ITERATION 1
NO. EVENTS--TOTAL 35 SCHEDULED 10 REPAIR 19 EMERGENCY 2 REPEATS 9 SUCCESSES 13 FAILURES 18 IGNORES 4
HOURS WORKED---TOTAL 92.7 SCHEDULED 55.2 REPAIR 21.6 EMER. 15.9 UNMANNED 89.6 AVG PERF ADEQ 0.90 AVG FAIL DIFF 0.072
PERCENTAGE OF---FAILURE 51.4 SUCC. 1ST TRY 37.1 SUCC. 2ND TRY 0. IGNORED 11.4 REPEATS 25.7
SAFETY INDEX 1.03 MENTAL LOAD 0.13 PERF EFF 0.192 HAZ. 67.
MAX. STRESS 3.18 ON EVENT 207 MAX. MENTAL LOAD 14. ON EVENT 225 MAX. CAL. EXPENDED 4200. ON EVENT 5 SEA STATE 9
CONS. BAL. (UNITS) 461 471 71 71 71 61 71 71 71 71
CONS. BAL. (UNITS/HR) 15120. 9970. 5970. 4970. 470. 470. 470. 470. 470. 470.

MAN NO.	TYPE	PHYSICAL CAP.	HOURS WORKED PRIM.	2ND	SLEPT	IDLE	FATIGUE	HEALTH INDEX	AVG PHYS WORKLOAD	COMPETENCE	ASPIRATION	PERFORM CUM.	NUMBER SUCC.
1	1	1.194	5.91	3.30	7.5	7.3	0.07	1.00	0.46	0.920	0.74	0.74	3.
2	1	1.097	6.40	0.	7.0	10.6	0.12	1.00	0.23	0.977	0.82	0.82	3.
3	3	0.856	10.02	0.	2.9	11.1	0.66	1.00	0.69	0.930	0.80	0.80	3.
4	4	1.021	4.00	4.25	7.5	8.3	0.	1.00	0.44	0.910	0.99	0.99	2.
5	6	0.902	18.44	0.	0.	5.6	0.96	1.00	2.30	0.925	0.11	0.16	3.
6	7	0.961	6.71	2.24	8.0	7.0	0.07	1.00	0.48	0.982	0.88	1.00	7.
7	8	0.872	12.00	0.	0.	12.0	1.00	1.00	1.30	0.966	0.07	0.13	2.
8	9	1.056	9.56	1.01	2.9	10.5	0.61	1.00	0.88	0.940	0.89	0.89	5.
9	10	0.943	8.89	0.	8.0	7.1	0.02	1.00	0.65	0.934	0.76	0.76	3.
AVERAGES PER MAN		0.989	9.10	1.20	4.9	8.8	0.39	1.00	0.83	0.943	0.67	0.70	3.44

AVERAGES BY TYPE

NO	TYPE												
2	1	1.145	6.16	0.	7.3	8.9	0.09	1.00	0.35	0.949	0.78	0.78	3.00
1	3	0.856	10.02	0.	2.9	11.1	0.66	1.00	0.69	0.930	0.80	0.80	3.00
1	4	1.021	4.00	0.	7.5	8.3	0.	1.00	0.44	0.910	0.99	0.99	2.00
1	6	0.902	18.44	0.	0.	5.6	0.96	1.00	2.30	0.925	0.11	0.16	3.00
1	7	0.961	6.71	0.	8.0	7.0	0.07	1.00	0.48	0.982	0.88	1.00	7.00
1	8	0.872	12.00	0.	0.	12.0	1.00	1.00	1.30	0.966	0.07	0.13	2.00
1	9	1.056	9.56	0.	2.9	10.5	0.61	1.00	0.88	0.940	0.89	0.89	5.00
1	10	0.943	8.89	0.	8.0	7.1	0.02	1.00	0.65	0.934	0.76	0.76	3.00

DAILY EQUIPMENT PERFORMANCE DATA

IO	CART	CDT	CUT	EPL
1	13.40	8.00	6.46	0.45
2	4.10	3.99	6.59	0.62
3	1.00	1.59	6.49	0.80

AEPL= 0.62 EPEFF= 0.85 EMTBF= 0.59 EMTTR= 6.17 SRL= 0.59 SPL= 0.89 SGEM= 0.16

Figure 2-12. Sample end-of-day recording.

Summarized are: the total number of events scheduled, events worked, repair events, emergency events, repeated events, successes, failures, and ignores, total hours worked, time spent on scheduled and repair and emergency events, unmanned station hours, average performance adequacy, average failure difference percentage of tasks failed and succeeded on first try, percentage of tasks succeeded on second try, and percentage of tasks ignored and repeated. Also, presented are: the safety index, competence increase, confidence, hazard, consumable balances, maximum stress and on which event, maximum mental load and on which event, maximum calories expended and on which event. A summary table is presented including for each man his physical capacity, hours worked in primary specialty, hours worked in secondary specialty, hours slept, hours idle, fatigue level, health index, average physical workload, competence, aspiration, performance (cumulative) and number of successes. Each of these variables is also averaged across the entire crew. A summary table of these variables is also presented by type of man.

Eleven reliability related variables are also summarized in the end-of-day printout. These are: average equipment performance level (AEPL), equipment performance effectiveness (EPEFF), equipment mean time between failures (EMTBF), equipment mean time to repair (EMTTR), system reliability level (SRL), system performance level (SPS), system general effectiveness (SGEM), and, for each equipment, equipment performance level (EPL), current average repairtime (CART), current down time (CDT), and current up time (CUT).

These same items are given in the third section of the end of day recording as a mean by type of man, where type is generally synonomous with work specialty.

End-of-Iteration Summary Calculations and Recordings

If the day just simulated was not the last day of the mission, then the day number, ND, is increased by one, and the entire process is repeated for the next and subsequent mission day's events by returning to circle c of the model flow chart.

After the last day has been simulated, several end-of-iteration summary calculations are made and the end-of-mission iteration record is made for later printing.

However, just prior to the recording, seven mission iteration human and equipment reliability summary measures are calculated as shown by their variable name below:

	Reliability		Availability
	MTBF	MTTR	
HUMAN	HMTBF	HMTTR	HAVAIL
EQUIPMENT	EMTBF	EMTTR	EAVAIL
SYSTEM	-	-	SYSAVAIL

These data are calculated from other available iteration summary values as shown in the flow chart at circle K, based upon the basic definitions of MTBF and MTTR and AVAIL = $\frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}}$.

The resultant recording of iteration output is then made. This recording contains such summary items as: number of events successful on first and second try, number of events failed and ignored, average man hours spent in primary specialty, in secondary specialty, hours spent sleeping and hours idle, consumables remaining, averages of physical load, mental load, competence, average performance adequacy, average fatigue, average aspiration, average health, and average safety. Each of these variables is also summarized as percentage of total, average per day, or percentage of original, whichever is appropriate. Summary by day (including an average across days) includes: number of repair or emergency events, average man hours spent doing repairs or handling emergencies, maximum stress, maximum mental load, confidence, hazard, average failure difference, number of successes and unmanned hours. A summary table by day and man type is provided for the following variables: physical capability, hours spent on primary and secondary specialties, sleep time, idle time, fatigue, health index, average physical work load, competence, aspiration, cumulative performance, and number of successes. Averages for these variables across types by day are also provided (Figure 2-13).

Reliability metrics provided at the end of each iteration are human mean time between failure (HMTBF), equipment mean time between failure (EMTBF), human mean time to repair (HMTTR), equipment mean time to repair (EMTTR), human availability (HAVAIL), and equipment availability (EAVAILL. A composite reliability metric of system availability (SYSAVAIL) is also provided.

Following each such mission iteration of ND days, a check is made to determine whether all N mission iterations have been completed. If not, the entire process, as described, begins again for the next iteration at circle a of the flow chart.

If N mission iterations have been accomplished, then the results of all of the N iterations are summarized, a new set of parameters is called into the computer and is recorded. The run summary tabulation output provides the summary of each and all iterations of the run in a tabular form which is similar to the iteration summary.

This entire process, then, results in the simulation of N iterations of a mission for each of several parameter sets and continues until the computer has processed all parameter sets provided as input.

```
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REPORT FOR ITERATION  1 OF  1 DAY MISSION---
DAY     NUMBER OF EVENTS          AVE, MAN HOURS SPENT                   ----------END OF DAY AVERAGES----------  INDICES
     SUC1 SUC2 FAIL IGNORE   PRIM, SECOND  SLEEP   IDLE                  PHYS LD  MEN LD  COMP   APA   FAT,  ASP  HLTH  SFTY
  1   13,   0,  18,     4,   9,10   1,20   4,87   8,83                    0,83    0,13  0,943  0,90  0,39  0,67  1,00  1,03

   ---PERCENT OF TOTAL---        AVERAGE PER DAY                                                    AVERAGE PER DAY
     37,1  0,  51,4  11,4    9,10   1,20   4,87   8,83                    0,83    0,13  0,943  0,90  0,39  0,67  1,00  1,03
CONS, BAL, (UNITS/HR)     15120,  9970,  5970,  4970,   470,   470,   470,   470,   470,   470,
PERCENT OF ORIGINAL       99,804 99,703 99,505 99,406 93,963 93,963 93,963 93,963 93,963 93,963
CONS, BAL, (UNITS)           461    471     71     71     71     61     71     71     71     71
PERCENT OF ORIGINAL       92,200 94,200 71,000 71,000 71,000 61,000 71,000 71,000 71,000 71,000

DAY     NUMBER OF EVENTS    AVE, MAN HOURS SPENT   MAX STRESS  MAX MEN LD   PERF EFF  HAZARD  AVG FL DIFF  NUMBER  UNMANNED   SEA
      REPAIR EMER   REPT     REPAIR EMERGENCY                                                              SUCC,    HOURS    STATE
  1     19,0   2,0   9,0     21,6          15,9        3,18       14,28       0,192   67,25        0,072    13,00     89,61   9,0

AVGS/DAY 19,0  2,0   9,0     21,6          15,9        3,18       14,28       0,192   67,25        0,072    13,00     89,61   9,0
```

AVERAGES BY TYPE OF PERSONNEL

NO,	TYPE	PHYSICAL CAP,	HOURS WORKED PRIM,	2ND	SLEPT	IDLE	FATIGUE	HEALTH INDEX	AVG PHYS WORKLOAD	COMPETENCE	ASPIRATION	PERFORM CUM,	NUMBER SUCC,
2	1	1,145	6,16	0,	7,3	8,9	0,09	1,00	0,35	0,949	0,78	0,78	3,00
1	3	0,856	10,02	0,	2,9	11,1	0,66	1,00	0,69	0,930	0,80	0,80	3,00
1	4	1,021	4,00	0,	7,5	8,3	0,	1,00	0,44	0,910	0,99	0,99	2,00
1	6	0,902	18,44	0,	0,	5,6	0,96	1,00	2,30	0,925	0,11	0,16	3,00
1	7	0,961	6,71	0,	8,0	7,0	0,07	1,00	0,48	0,982	0,88	1,00	7,00
1	8	0,872	12,00	0,	0,	12,0	1,00	1,00	1,30	0,966	0,07	0,13	2,00
1	9	1,056	9,56	0,	2,9	10,5	0,61	1,00	0,88	0,940	0,89	0,89	5,00
1	10	0,943	8,89	0,	8,0	7,1	0,02	1,00	0,65	0,934	0,76	0.76	3,00

AVERAGES PER DAY FOR EACH MAN

NO,	TYPE	PHYSICAL CAP,	HOURS WORKED PRIM,	2ND	SLEPT	IDLE	FATIGUE	HEALTH INDEX	AVG PHYS WORKLOAD	COMPETENCE	ASPIRATION	PERFORM CUM,	NUMBER SUCC,
1	1	1,194	5,91	3,30	7,5	7,3	0,07	1,00	0,46	0,920	0,74	0,74	3,00
2	1	1,097	6,40	0,	7,0	10,6	0,12	1,00	0,23	0,977	0,82	0,82	3,00
3	3	0,856	10,02	0,	2,9	11,1	0,66	1,00	0,69	0,930	0,80	0,80	3,00
4	4	1,021	4,00	4,25	7,5	8,3	0,	1,00	0,44	0,910	0,99	0,99	2,00
5	6	0,902	18,44	0,	0,	5,6	0,96	1,00	2,30	0,925	0,11	0,16	3,00
6	7	0,961	6,71	2,24	8,0	7,0	0,07	1,00	0,48	0,982	0,88	1,00	7,00
7	8	0,872	12,00	0,	0,	12,0	1,00	1,00	1,30	0,966	0,07	0,13	2,00
8	9	1,056	9,56	1,01	2,9	10,5	0,61	1,00	0,88	0,940	0,89	0,89	5,00
9	10	0,943	8,89	0,	8,0	7,1	0,02	1,00	0,65	0,934	0,76	0,76	3,00
AVERAGES		0,989	9,10	1,20	4,9	8,8	0,39	1,00	0,83	0,943	0,67	0,70	3,44

EMTBF= 0,590   EMTTR= 6,167

Figure 2-13. Sample end-of-iteration recording.

CHAPTER III

INITIAL MODEL APPLICATION--SENSITIVITY TESTS

The model described in Chapter II was applied to a hypothetical mission. The mission was developed specifically for assessing the logic of the model's output and for obtaining an initial estimate of its internal validity. The mission was general in scope and involved typical work events as found in many Navy shore and sea based systems. However, the mission was not intended to reflect accurately any specific mission. Rather, it was developed to provide a basis for experiencing and evaluating the model's internal structure and its output. Such a hypothetical mission possesses advantage because certain model features may be inadequately tested in a usual mission. For example, emergencies or repairs would occur so infrequently that test of features related to these variables would be insensitive or require an inordinately large number of iterations per run.

This chapter discusses the mission developed, the related input data, and the results obtained from the sensitivity test analysis.

Mission Events

The mission developed for model sensitivity test involved 27 events. These were subdivided into 10 scheduled events, 14 repair events, and 3 emergency events. All 27 events could occur on any given day with stochastic processes determining both the actual events which occurred, as well as their sequence of occurrence.

Scheduled Events

The 10 scheduled events were subdivided into two scheduled event families with four and two events, respectively, and four single events. Figure 3-1 shows a sample portion of the computer tabulation of the scheduled event input data. The following explanation of scheduled event 3 (Figure 3-1) illustrates the meaning of the data relative to this event. Scheduled event 3 employs event type number 11 (IETYP = 11), uses the third set of thresholds for units per hour consumable consumption (TSR = 3), uses the second set of thresholds for units consumable consumption (TSRI = 2), and is neither the first nor the last event (IFOI = 0) in family two (IEFW = 2), which consists of four events (NIF = 4). Also, scheduled event 3 is followed by scheduled event 4 [NX(1) = 4 and PRB(1) = 1.00]. Before scheduled event 3 can be started, precedent event 1 (IPE = 1) must be completed. Scheduled event 3 can be touched up (RTU = 2)and must be completed by time limit 0730 hours (TL = 7.30). It must start by 0345 hours (ST = 3.75).

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APPLIED PSYCHOLOGICAL SERVICES--NAVSEA HURI AIS,MRL,JJW,JB          11/05/74        PAGE    9
                                                                            SCHEDULED EVENT DATA
 ND= 1      NOSE= 10     DAY 1 TEST
  IE  IETYP  TS  TS1  IFOI  NIF  IEFN    NX(1-3)        PRB(1-3)       IPE  RIU      TL    ST
      IEDC(1-3)EDCV(1-3)

   1      9   2    3    1    4     2    2   2   2  1,00  0.    0.      0    1    4.00  0.
        0  0  0    0.        0.        0.

   2     10   3    4    0    4     2    3   4   4  0,50  0.50  0.      0    1   24.00  6,00
        0  0  0    0.        0.        0.

   3     11   3    2    0    4     2    4   4   4  1,00  0.    0.      1    2    7.30  3,75
        0  0  0    0.        0.        0.

   4     12   3    2    2    4     2    5   5   5  1,00  0.    0.      1    2   24.00  4,00
        0  0  0    0.        0.        0.

   5     20   2    2    1    1     5    6   6   6  1,00  0.    0.      1    3   16.00 11,75
        0  0  0    0.        0.        0.

   6     21   1    2    1    1     6    7   7   7  1.00  0.    0.      0    1   20.00  6,00
        0  0  0    0.        0.        0.

   7     22   1    2    1    1     7    8   8   8  1,00  0.    0.      0    1   20.60  6,00
        0  0  0    0.        0.        0.

   8     23   1    3    1    1     8    9   9   9  1,00  0.    0.      0    2   24.00  6,00
        0  0  0    0.        0.        0.
```

Figure 3-1. Sample sensitivity test input data for scheduled events.

Repair Events

The 14 repair events were subdivided into two repair families with eight and five events, respectively, and one single repair event. The eight repair event family was designated as repairing electronic equipment. The five repair event family was designated as repairing electromechanical equipment, while the single repair event involved a mechanical repair. Figure 3-2 shows a sample of the computer tabulation of the repair event input data. The following explanation of the third event in the electronic repair family describes the meaning of the input data for repair events. This repair event employs event type number (TYPE = 3) with event 2 as the next event to be performed [NX(1) = 202; 202-200 = 2 with 200 subtracted as repair events begin at that location in memory] with a probability equal to 1.0 [PRB(1) = 1.0]. If performed unsuccessfully, the event is not repeated or touched up (RTU = 0). There is no required precedent event (IPE = 0). Repair event 3 is not the first or the last event (IFOI = 0) in family 1 (IEFN = 1), which is composed of a total of eight repair events (IRE = 8) Like all other events in this family which is employed in corrective maintenance of electronic equipment number 1 (IQ = 1), no data change options are in effect [IEDC(1-3) = 0; IEDC (1-3) = 0). Equipment 1 has: a reliability of 0.1 (RELH = 0.1), an intermittent failure rate of 1.00 (TUI = 1.0) per hour, and a maximum repair time of 5.00 hours (DTR = 5.00).

Emergency Events

No families are involved in the simulation of the emergencies. Three types of emergencies were included in the sensitivity test data. Figure 3-3 presents the computer tabulation of the emergency event input. The data for emergency event 2 (K = 2) will serve as an example. The average event time is expected to be .70 hours (ART = .70), with a standard deviation of .10 (ASDE = 0.10), and a maximum of 1.20 hours (DTE = 1.20). The rate of consumable expenditures (units per hour) is shown to be 10 for consumables one through four [IRCE(1-4) = 10] and zero for consumables six through ten [IRCE(6-10) = 0]. The threshold set used for these consumables is 1 (TSE = 1). The rate of consumable expenditure (units) is shown to be five for consumables one through five [IRCE1(1-5) = 5] and 10 for consumables six through 10 [IRCE1(6-10) = 10]. The threshold set used for these consumables is also 1(TSE1 = 1). The mental load involved in this task is 2(LODME = 2), the essentiality is 75(IESSE = 75), and the hazard class is 2(IHE = 2). Seven men are necessary for this emergency with types (NREQE)--and expected energy consumption by type (IECE) in parenthesis--one [IECE(1) = 180), two [IECE(2) = 180), four [IECE(4) = 638], eight [IECE(8) = 720], nine [IECE(9) = 720], and ten [IECE(10) = 720] required. Two type 10 men are required [NREQE(10) = 2].

```
          APPLIED PSYCHOLOGICAL SERVICES--NAVSEA HURT AIS,MRL,JJW,JB                    11/05/74             PAGE      3
                                                                                                 EQUIPMENT REPAIR EVENT DATA
   IQ  DESCRIPTION                                                               TSR,  TSR1      RELH     TUI   DTR
  TYPE  NX(1-3)       PRB(1-3)   RTU IEDC(1-3)   IEDCV(1-3)                  IPE  IFOI  IRE   IEFN

    1  ELECTRONIC REPAIR 1                                                          1     1  0.100000   1.00 5.00
    1 202 203 208 0.85 0.10 0.05 1 0  0  0      0.        0.        0.     0     1     8     1
    2 204 205 205 0.50 0.50 0.    0 0  0  0      0.        0.        0.     0     0     8     1
    3 202 200 200 1.00 0.   0.    0 0  0  0      0.        0.        0.     0     0     8     1
    4 205 206 200 0.20 0.80 0.    0 0  0  0      0.        0.        0.     0     0     8     1
    5 204 206 200 0.20 0.80 0.    0 0  0  0      0.        0.        0.     0     0     8     1
    6 207 200 200 1.00 0.   0.    0 0  0  0      0.        0.        0.     0     0     8     1
    7 208 200 200 1.00 0.   0.    0 0  0  0      0.        0.        0.     0     0     8     1
    8 200 200 200 1.00 0.   0.    1 0  0  0      0.        0.        0.     0     2     8     1

    2  ELECTROMECHANICAL REPAIR 1                                                   2     2  0.300000   2.0060.00
   14 214 212 212 1.00 0.   0.    1 0  0  0      0.        0.        0.     0     1     5     3
   15 215 212 212 1.00 0.   0.    2 0  0  0      0.        0.        0.     0     0     5     3
   16 216 212 212 1.00 0.   0.    1 0  0  0      0.        0.        0.     0     0     5     3
   17 217 212 212 1.00 0.   0.    3 0  0  0      0.        0.        0.     0     0     5     3
   18 212 212 212 1.00 0.   0.    3 0  0  0      0.        0.        0.     0     2     5     3

    3  MECHANICAL REPAIR 1                                                          1     1  1.000000   3.0010.00
   19 224 224 224 1.00 0.   0.    3 0  0  0      0.        0.        0.     0     1     1     4
```

Figure 3-2. Sample sensitivity test input data for repair events.

```
APPLIED PSYCHOLOGICAL SERVICES--NAVSEA HURT AIS,MRL,JJW,JB                  11/05/74          PAGE    4
                                                                                  EMERGENCY EVENT DATA
  K    IDENTIFIER
 NDRE  ART   ASDE  DTE                                                 IRCE(1-10)             TSE   LODME  IESSE
          NREDE(1-10)                                                  IRCE1 (1-10)           TSE1   IHE
          IECE(1-10)

   1        EMERGENCY 1
     1 1,00   0,05 1.20        1,     1,     1,     1,     1,     1,     1,     1,     1,     1, 1      2,    100
  3  1  1  1  1  1  1  1  1  2    1      1      1      1      1      1      1      1      1     1 1      2,
 192,  262,  150,  216,  216,  144,  144,  144,  216,  216,
   2        EMERGENCY 2
     2 0,70   0,10 1.00       10,    10,    10,    10,    10,     0,     0,     0,     0,     0, 1      3,     75
  1  1  0  1  0  0  0  1  1  2    5      5      5      5      5     10     10     10     10    10 1      2,
 180,  180,    0,  638,    0,    0,    0,  720,  720,  720,
   3        EMERGENCY 3
     1 0.35   0,10 0.90        1,     1,     1,     1,     2,     2,     2,     2,     2,     2, 1      3,     99
  1  0  0  0  0  0  0  0  1  0    5      5      5      5      5      5      5      5      5     5 2      1,
 144,    0,    0,    0,    0,    0,    0,    0,  216,    0,
```

Figure 3-3. Sensitivity test input data for emergency events.

Event Types

Scheduled and repair events are all associated with event type data. This feature allows flexibility to the analyst in coupling events with different critical parameter values. Figure 3-4 presents a sample portion of the computer tabulation of the event type data. Event type 11 (J = 11), which is associated with scheduled event 3 (explained earlier), will serve to illustrate the meaning of the event type data input entries. This decision event type has an essentiality of 99 (IESS = 99), a mental load of 2 (LODM = 2), and a fixed end time (KE = 1). It is not a training event (INT = 1), has a hazard class of 1 (IH = 1), and requires five men with types (NREQE)--and expected energy consumption by type (IECE) in parenthesis--two [IECE(2)= 216], five [IECE(5) = 216], seven [IECE(7) = 216], nine [IECE(9) = 250], and ten [IECE(10) = 250]. This event type has an expected average duration of five hours (ADUR = 5) and an average duration standard deviation of 0. 1 hours (ASD =.1). The class of the event is 3 (CLASS = 3), and one equipment (NIQR = 1) is required --equipment number one [IQR(1) = 1]. The expected consumable usage in units per hour is one [IRC(1-10) = 1] and in units it is also one [IRC1(1-10) = 1].

Parameters

Computer input data were selected so as to allow initial exercise of the major model features.

Following data preparation, a variety of computer simulation runs was completed employing a range of parameter values in order to allow evaluation of the sensitivity of the model to variations in parametric input and how they affect various reliability metrics.

Table 3-1 shows the nominal values, or conditions, for each computer run performed.

Table 3-2 presents the matrix which was used in the assignment of personnel crosstraining probabilities. This matrix presents the probability of a personnel type with a given primary specialty being crosstrained in a given secondary specialty. These values were obtained through interviews with persons who were patrol boat members and were used in the Siegel et al. (1972) study.

The parameter values varied for the seven sensitivity test runs are shown in Table 3-3. Each set of values in a computer run was designated a "parameter set" and numbered one to seven, as shown in Table 3-3. These parameter values allow the comparison of such effects as varying workday length, crew proficiency, and sea state on output measures such as the number of repairs successfully completed.

```
APPLIED PSYCHOLOGICAL SERVICES--NAVSEA HURT AIS,MRL,JJW,JB                       11/05/74            PAGE    5

                                            EVENT TYPE DATA
   J    IDENTIFIER                                                               ADUR    ASD CLASS  NIQR        IQR(1-6)

 IESS    LOOM  KE INT  IH    NREQ(1-10)                         IRC(1-10)
                IFC(1-10)                                       IRC1(1-10)

   1   EVENT TYPE 1 ELECTRONIC REPAIR--10 EO                                     1.000  0.250   10     1   1   0   0   0   0   0
 100      5.   2   1  3.  0  0  0  0  0  1  0  1  0  0      1.     1.     1.     1.     1.     1.     1.     1.     1.     1.
   0.   0.   0.   0.   0. 374.   0. 374.   0.   0.             1      1      1      1      1      1      1      1      1      1

   2   EVENT TYPE 2 ELECTRONIC REPAIR--7 EC                                      1.100  0.250    7     1   1   0   0   0   0   0
 100      5.   2   1  3.  0  0  0  0  0  1  0  1  0  0      1.     1.     1.     1.     1.     1.     1.     1.     1.     1.
   0.   0.   0.   0.   0. 374.   0. 374.   0.   0.             1      1      1      1      1      1      1      1      1      1

   3   EVENT TYPE 3 ELECTRONIC REPAIR--12 EI                                     1.000  0.100   12     1   1   0   0   0   0   0
 100      5.   2   1  3.  0  0  0  0  0  1  0  1  0  0      1.     1.     1.     1.     1.     1.     1.     1.     1.     1.
   0.   0.   0.   0.   0. 374.   0. 374.   0.   0.             1      1      1      1      1      1      1      1      1      1

   4   EVENT TYPE 4 ELECTRONIC REPAIR--8 ECA                                     1.100  0.100    8     1   1   0   0   0   0   0
 100      5.   2   1  3.  0  0  0  0  0  1  0  1  0  0      1.     1.     1.     1.     1.     1.     1.     1.     1.     1.
   0.   0.   0.   0.   0. 374.   0. 374.   0.   0.             1      1      1      1      1      1      1      1      1      1

   5   EVENT TYPE 5 ELECTRONIC REPAIR--6 EURM                                    1.000  0.250    6     1   1   0   0   0   0   0
 100      5.   2   1  3.  0  0  0  0  0  1  0  1  0  0      1.     1.     1.     1.     1.     1.     1.     1.     1.     1.
   0.   0.   0.   0.   0. 374.   0. 374.   0.   0.             1      1      1      1      1      1      1      1      1      1

   6   EVENT TYPE 6 ELECTRONIC REPAIR--9 ER,                                     1.000  0.250    9     1   1   0   0   0   0   0
 100      5.   2   1  3.  0  0  0  0  0  1  0  1  0  0      1.     1.     1.     1.     1.     1.     1.     1.     1.     1.
   0.   0.   0.   0.   0. 374.   0. 374.   0.   0.             1      1      1      1      1      1      1      1      1      1

   7   EVENT TYPE 7 ELECTRONIC REPAIR--10 EO                                     1.000  0.200   10     1   1   0   0   0   0   0
 100      5.   2   1  3.  0  0  0  0  0  1  0  1  0  0      1.     1.     1.     1.     1.     1.     1.     1.     1.     1.
   0.   0.   0.   0.   0. 374.   0. 374.   0.   0.             1      1      1      1      1      1      1      1      1      1

   8   EVENT TYPE 8 ELECTRONIC REPAIR--13 ERPI                                   1.000  0.200   13     1   1   0   0   0   0   0
 100      5.   2   1  3.  0  0  0  0  0  1  0  1  0  0      1.     1.     1.     1.     1.     1.     1.     1.     1.     1.
   0.   0.   0.   0.   0. 374.   0. 374.   0.   0.             1      1      1      1      1      1      1      1      1      1

   9   EVENT TYPE 9--COMMUNICATE                                                 4.000  0.200    1     1   2   0   0   0   0   0
  99      2.   1   1  1.  0  0  0  1  0  0  0  1  0  2      1.     1.     1.     1.     1.     1.     1.     1.     1.     1.
   0.   0.   0. 216.   0.   0.   0. 216.   0. 250.             1      1      1      1      1      1      1      1      1      1

  10   EVENT TYPE 10--OPERATE                                                    1.000  0.200    2     1   3   0   0   0   0   0
  95      1.   2   1  1.  0  0  0  0  0  1  0  0  0  0      1.     1.     1.     1.     1.     1.     1.     1.     1.     1.
   0.   0.   0.   0.   0. 135.   0.   0.   0.   0.             1      1      1      1      1      1      1      1      1      1

  11   EVENT TYPE 11 DECIDE                                                      5.000  0.100    3     1   1   0   0   0   0   0
  97      2.   1   1  1.  0  1  0  0  1  0  1  0  1  1      1.     1.     1.     1.     1.     1.     1.     1.     1.     1.
   0. 216.   0.   0. 216.   0. 216.   0. 250. 250.             1      1      1      1      1      1      1      1      1      1

  12   EVENT TYPE 12 ACT                                                         1.100  0.100    4     1   1   0   0   0   0   0
  95      4.   2   1  1.  0  0  0  0  0  1  0  0  0  0      1.     1.     1.     1.     1.     1.     1.     1.     1.     1.
   0.   0.   0.   0.   0. 170.   0.   0.   0.   0.             1      1      1      1      1      1      1      1      1      1
```

Figure 3-4. Sample sensitivity test event type input data.

Table 3-1

"Standard" Parameter Set Run Conditions

Parameter	*FORTRAN*	*Value*
Average psychological stress threshold	APST	2.30
Workday, assignment limit	WORK1	varied
Workday, maximum	WORK2	22.00
Hours since last sleep at start	SLEEP	1.00
Catnap threshold	CN	1.00
Maximum sleep permitted per day	MAXSL	8.00
Fatigue threshold	TFAT	0.25
Average crew pace	ACP	varied
Average daily calories per crew member	CALRY	2700.00
Average short term power rate (cals/hr)	PWRRT	440.00
Acceptable performance constant	K7	1.00
Work factor constant	K1	0.95
Consumable levels: (units/hr)	KON(1)	15150.00
	KON(2)	10000.00
	KON(3)	6000.00
	KON(4)	500.00
	KON(5)	500.00
	KON(6)	500.00
	KON(7)	500.00
	KON(8)	500.00
	KON(9)	500.00
	KON(10)	500.00
Consumable levels: (units)	KON1(1)	100.00
	KON1(2)	100.00
	KON1(3)	100.00
	KON1(4)	100.00
	KON1(5)	100.00
	KON1(6)	100.00
	KON1(7)	100.00
	KON1(8)	100.00
	KON1(9)	100.00
	KON1(10)	100.00
Initial aspiration level	AASP	0.85
Number of iterations	N	5.00
Essentiality threshold	IET	0.30
Sea state	SESTA	varied
Personnel Data		
Mean body weight of total population	WT	160.50
Standard deviation of population body weight	SIGWT	20.00
% crew fully qualified in prime specialty	PPFQ	varied
% crew minimally qualified in prime specialty	PPMQ	varied
% crew unqualified in prime specialty	PPUQ	varied
% crew fully qualified in second specialty	SPFQ	varied
% crew minimally qualified in second specialty	SPMQ	varied
% crew unqualified in second specialty	SPUQ	varied
Avg. N man days between physical incapacitations	MPI	5.00
Avg. duration of incapacity (days)	PID	5.00
Physical capability constant, a value yielding zero physical capability due to over exertion	ZPC	2.00
Number of men by type	MEN(ICE,NI)	varied

Table 3-2

Crosstraining Probability Matrix

Secondary Specialty	*Prime Specialty* 1	2	3	4	5	6	7	8	9	10
1	0.99	0.65	0.71	0.25	0.09	0.18	0.18	0.13	0.11	0.05
2	0.78	1.00	0.65	0.63	0.31	0.45	0.38	0.23	0.26	0.59
3	0.79	0.46	1.00	0.11	0.13	0.12	0.43	0.16	0.35	0.06
4	0.56	0.72	0.24	1.00	0.71	0.35	0.21	0.16	0.19	0.42
5	0.38	0.27	0.12	0.62	0.94	0.14	0.26	0.32	0.12	0.13
6	0.36	0.22	0.42	0.06	0.21	1.00	0.52	0.54	0.25	0.06
7	0.81	0.39	0.72	0.14	0.42	0.72	1.00	0.86	0.48	0.14
8	0.21	0.06	0.12	0.10	0.47	0.37	0.55	1.00	0.08	0.03
9	0.26	0.16	0.85	0.04	0.04	0.60	0.23	0.18	0.96	0.06
10	0.83	1.00	0.82	0.97	0.87	0.71	0.82	0.73	0.74	1.00

Table 3-3

Sensitivity Test Runs

Parameters Varied	Parameter Set--Test Run 1	2	3	4	5	6	7	Comparison
Workday length (hours)	18	18	18	12	12	12	18	Average vs. long workday
Primary proficiency								
1. Per cent fully qualified	0	0	0	90	90	90	0	High proficiency vs.
2. Per cent minimally qualified	10	10	10	10	10	10	10	low proficiency crew
3. Per cent unqualified	90	90	90	0	0	0	90	
Secondary proficiency								
1. Per cent fully qualified	0	0	0	90	90	90	0	High proficiency vs.
2. Per cent minimally qualified	10	10	10	10	10	10	10	low proficiency crew
3. Per cent unqualified	90	90	90	0	0	0	90	
Average crew pace	1.0	1.0	1.0	1.0	1.0	1.0	1.25	Average vs. slow crew
Sea state	9	9	0	0	9	0	0	Calm vs. rough seas
Crew size	14	9	9	14	9	9	9	Large vs. small crew

Table 3-4 shows the personnel assignment matrices for crew echelon by personnel type for the two crew sizes (9 men and 14 men) simulated. The decrease in crewsize from 14 to 9 results in the loss of one type one man from crew echelon one, one type two man from crew echelon two, one type five man from crew echelon three, and two type ten men from crew echelon four.

Table 3-4

Personnel Assignment Matrices for Crew Sizes of 9 and 14

Crew Size of 9

		Personnel Type									
		1	2	3	4	5	6	7	8	9	10
Crew Echelon	1	2	0	0	0	0	0	0	0	0	0
	2	0	0	1	1	0	0	0	0	0	0
	3	0	0	0	0	0	1	1	1	0	0
	4	0	0	0	0	0	0	0	0	1	1

Crew Size of 14

		Personnel Type									
		1	2	3	4	5	6	7	8	9	10
Crew Echelon	1	3	0	0	0	0	0	0	0	0	0
	2	0	1	1	1	0	0	0	0	0	0
	3	0	0	0	0	1	1	1	1	0	0
	4	0	0	0	0	0	0	0	0	1	3

Note that a variety of differences were selected in an attempt to assess effects on the model's output for sensitivity evaluation. These changes in output, when viewed in the light of input change, may be used to determine the realism (agreement with logical expectancy) of model's output responses both in direction and magnitude. To allow appraisal of the model's sensitivity, the results achieved will be presented in groups of parameter set runs which concentrate on a selected facet of the model's response. For example, parameter sets 1 and 2 allow a determination of the effect of crew size. The only change in parameter values between the two computer runs is crew size. Similarly, a comparison between parameter sets 3 and 7 allows quantification of the effects of variation in average crew pace.

Results

Crew Size

The results from parameter set 1 versus 2 and 4 versus 6 represent the effects of variations in crew size on the completion of the events in the simulated day's work. Parameter sets 2 and 6 include crew sizes of 9 men, while parameter sets 1 and 4 are simulations of crews with 14 men. Parameter sets 1 and 2 both involve: long workdays, low proficiency crews, average crew pace, and rough seas. Parameter sets 4 and 6 both include: short workdays, high proficiency crews, average crew pace, and calm seas.

Figures 3-5, 3-6, 3-7, and 3-8 present the effects of crew size variation on selected simulation output. The first of these figures indicates for both comparisons an increasing percentage of tasks successfully completed with increasing crew size. The percentage of tasks failed decreased from 71.2 to 65.9 with increasing crew size for parameter sets 1 and 2, while the percentage of tasks failed for parameter sets 4 and 6 remained relatively constant. The effects of crew size variation on task performance accordingly seems to have had its greatest impact on the percentage of tasks successfully completed. Task success percentage increased approximately 10 per cent for parameter sets 1 and 2 (less than optimal conditions) and approximately 15 per cent for parameter sets 4 and 6 (with more optimal conditions). Increases in the number of events failed with smaller crews seems to be coupled with less than optimal conditions. Large simulated crews were more able to handle the increased workload. This result seems to be in accordance with logical expectancy.

Figure 3-6 indicates, as would be expected, that more idle hours and less work by crew members in their primary proficiency accompanies larger crew sizes. Idle time was about 20 per cent greater for parameter set 1 as compared with parameter set 2 and about 10 per cent greater for parameter set 4 as compared with parameter set 6. The decrease in time worked in primary specialty is reflective of the general decrease in work time per crew man with increasing crew size. This trend of these results is also considered to be realistic.

Figure 3-7 presents the effect of crew size on average physical workload. As expected, increasing the size of the crew results in a simulation output which indicated less physical workload per crew member. The difference in workload between parameter sets 1 and 2 (less than optimal conditions) and parameter sets 4 and 6 (more optimal conditions) reflects the greater number of events attempted (not ignored) and successfully performed (see Figure 3-5) by the simulated crew under the more optimal conditions.

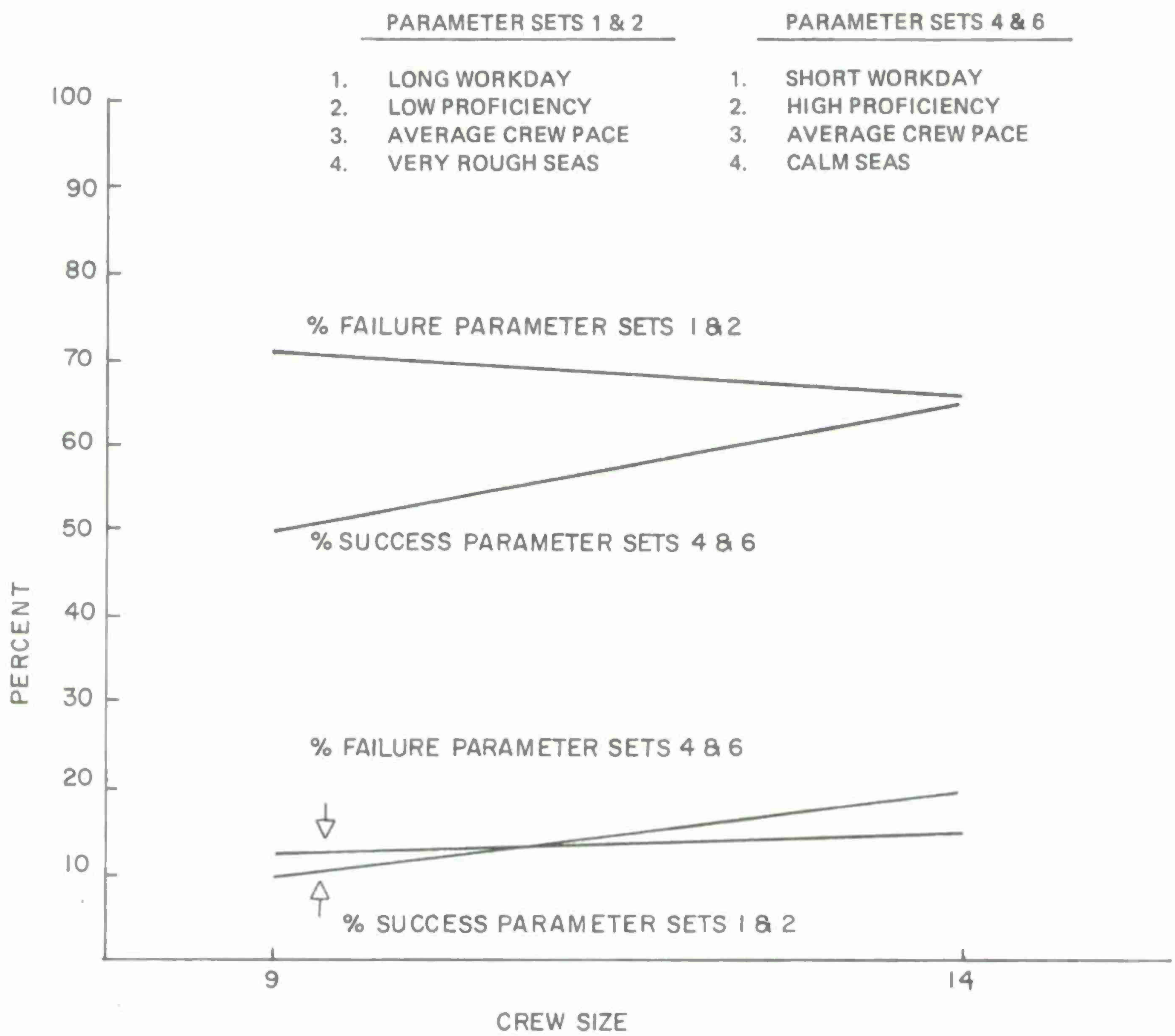

FIGURE 3-5. EVENT SUCCESS AND FAILURE PERCENTAGE AS A FUNCTION OF CREW SIZE.

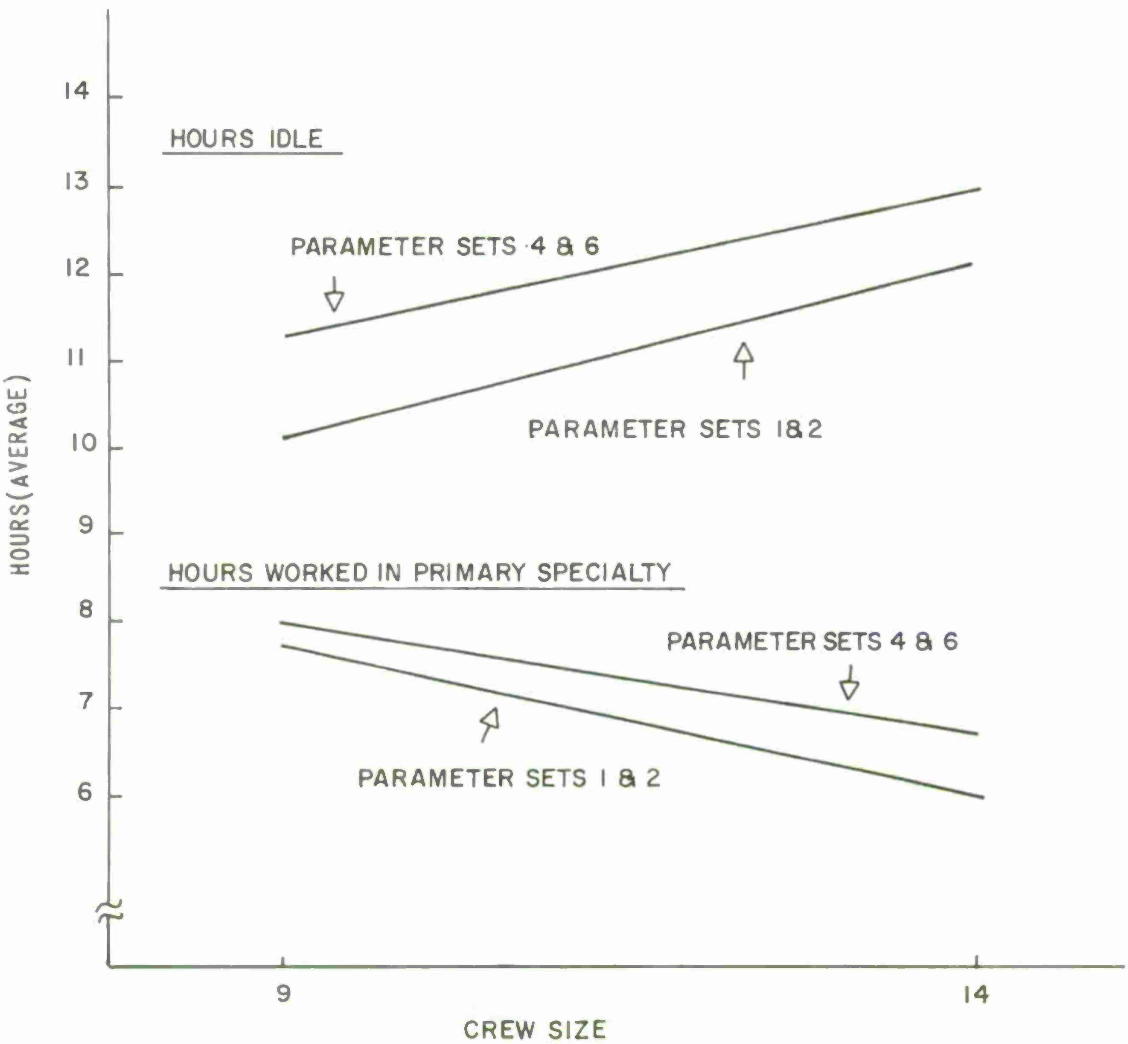

FIGURE 3-6. HOURS (AVERAGE) WORKED IN PRIMARY SPECIALTY AND HOURS IDLE AS A FUNCTION OF CREW SIZE.

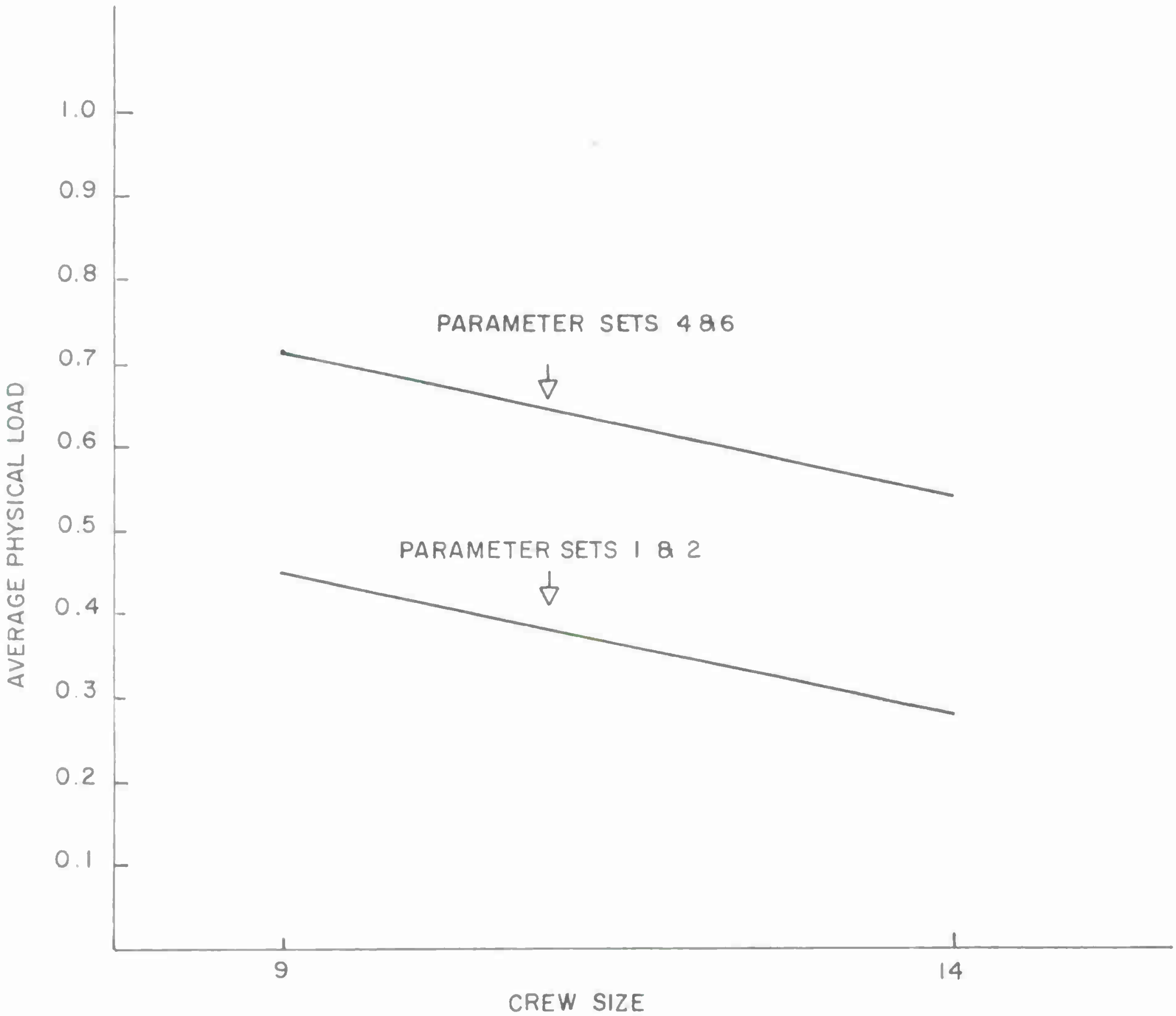

FIGURE 3-7. AVERAGE PHYSICAL LOAD AS A FUNCTION OF CREW SIZE.

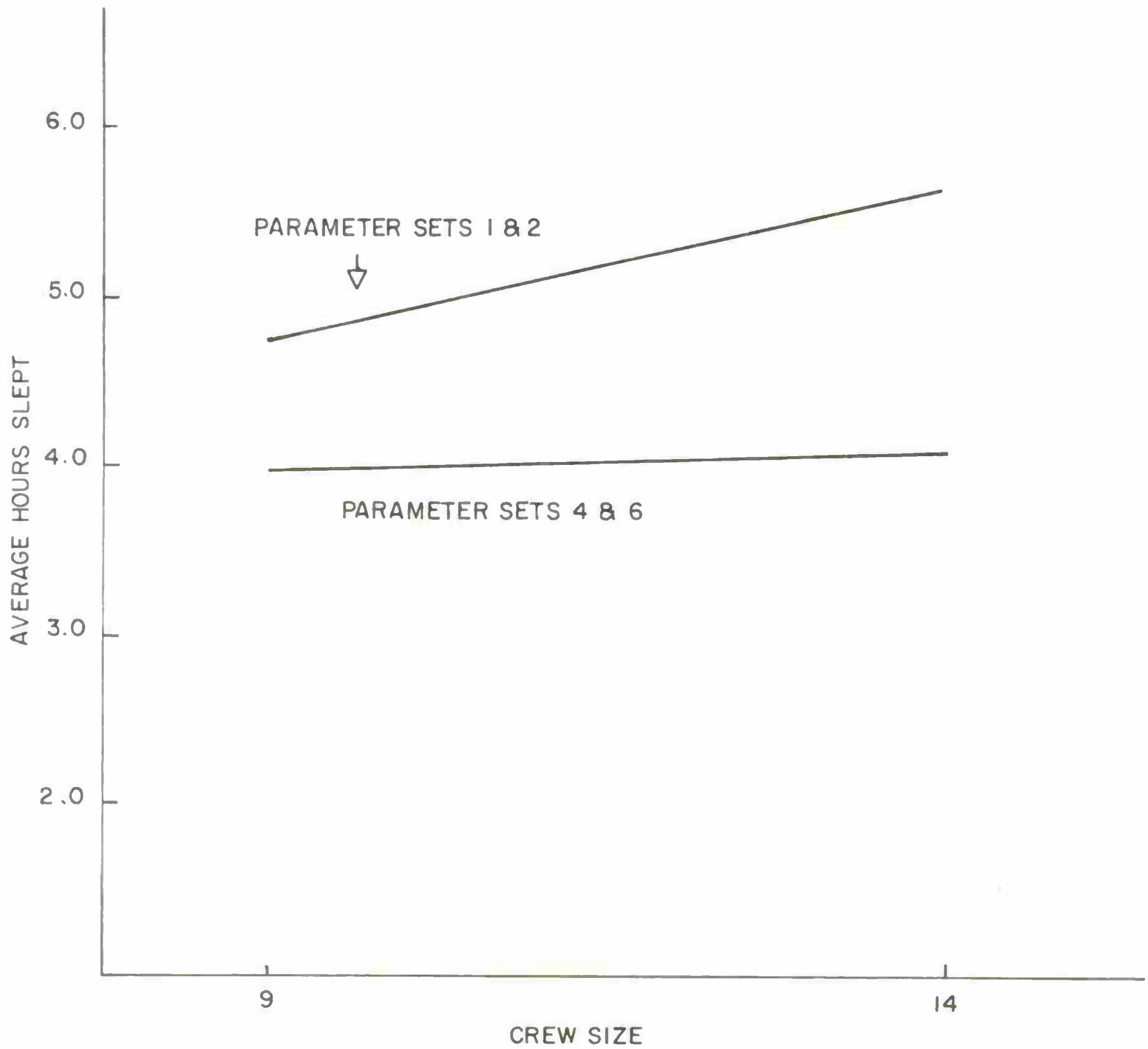

FIGURE 3-8. AVERAGE HOURS SLEPT AS A FUNCTION OF CREW SIZE

The effect on average hours slept of variations in crew size is shown in Figure 3-8. With increasing crew size, the average number of hours slept can be observed to increase for parameter sets 1 and 2, as well as parameter sets 4 and 6. The effect is marginal for parameter sets 4 and 6. For parameter sets 1 and 2, approximately a 20 per cent increase in sleep time was shown with the increased crew size. The increased sleep time available under the more adverse conditions (parameter sets 1 and 2) is a function of more events being ignored.

The crew size data suggest that the crew size variable is adequately and logically reflected on a number of the model's output variables. This variable seems to have the desired effects on event success, failure, hours worked, idle time, hours slept, and physical workload levels.

Sea State

The effect of the sea state parameter on the model's output was explored by comparing the simulation results from: (1) parameter sets 2 and 3, and (2) parameter sets 5 and 6. Parameter sets 2 and 3 are characterized by: long workdays, low proficiency crews, average crew pace, and small crews. Parameter sets 5 and 6 are characterized by: short workdays, high proficiency crews, average crew pace, and small crews. Parameter sets 2 and 5 have sea state values equal to 9 (rough seas) while parameter sets 3 and 6 have sea state values equal to 0 (calm and glassy) seas.

The effects of variation in the sea state parameter are shown in Figures 3-9, 3-10, and 3-11. Figure 3-9 shows the effect of sea state variation on the average failure difference. As anticipated, both parameter sets indicated a larger margin between actual and acceptable performance (the failure difference) for the rough sea state condition. The larger failure differences observed for parameter set 2 as compared with parameter set 3 suggest that, according to the model, a lower proficiency crew working a longer worker day will suffer a significant performance degradation in rough seas and that this degradation is higher than for the short workday, high proficiency crews.

Figure 3-10 presents the effects on the percentage of events successfully completed or failed as a function of difference in sea state. Percentage of failure appears to increase significantly with adverse weather conditions. The effects on percentage of success appear to have been greatest in the comparison of parameter set 2 with parameter set 3. Here, a 14 per cent decrease was indicated. The slight increase in percentage of successful events observed for parameter set 5 as compared with parameter set 6 (adverse weather conditions)(4 per cent) is consistent with the prior indication of the model that higher proficiency crews working shorter workdays are less affected by the sea state.

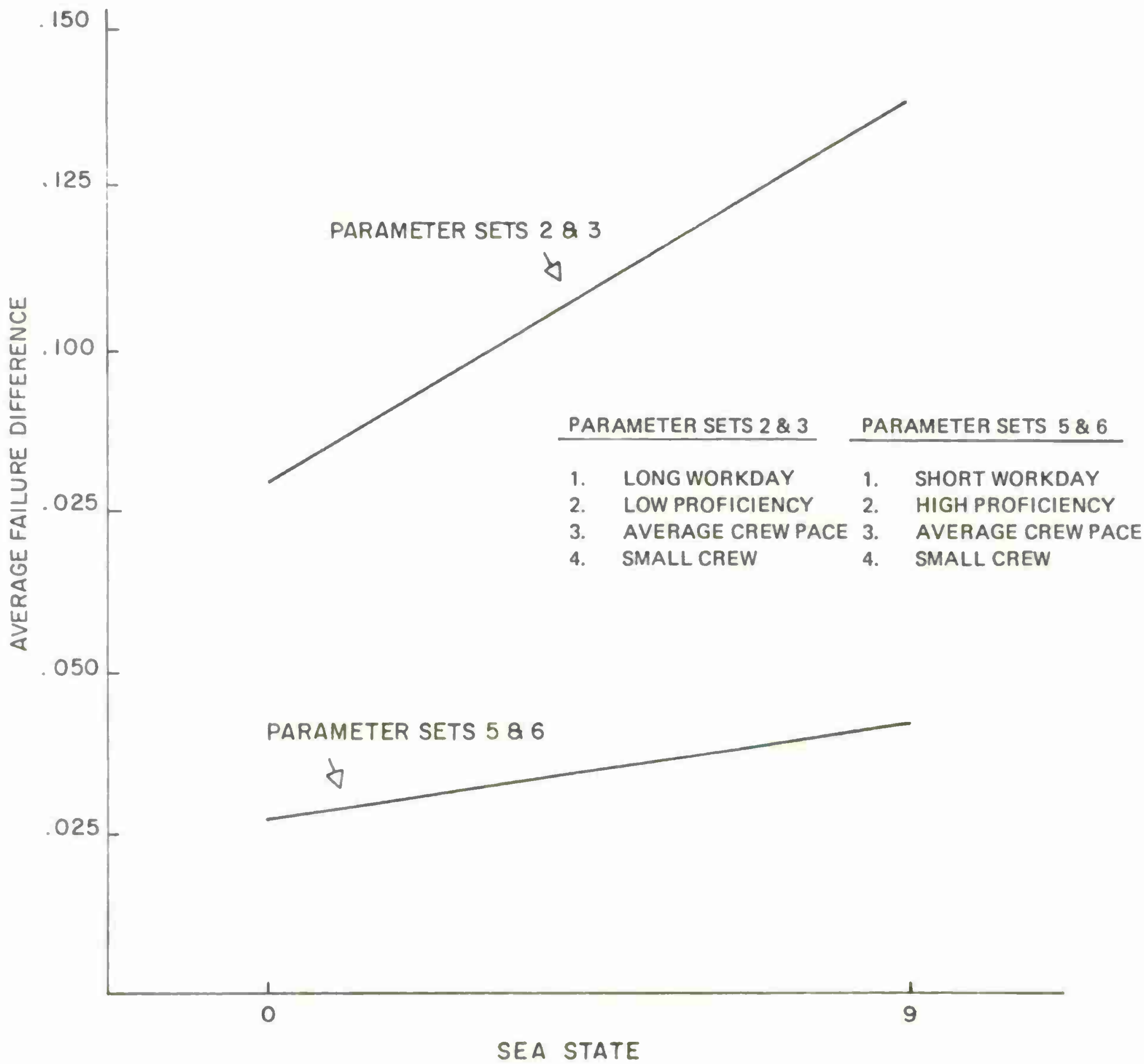

FIGURE 3-9. AVERAGE FAILURE DIFFERENCE AS A FUNCTION OF SEA STATE.

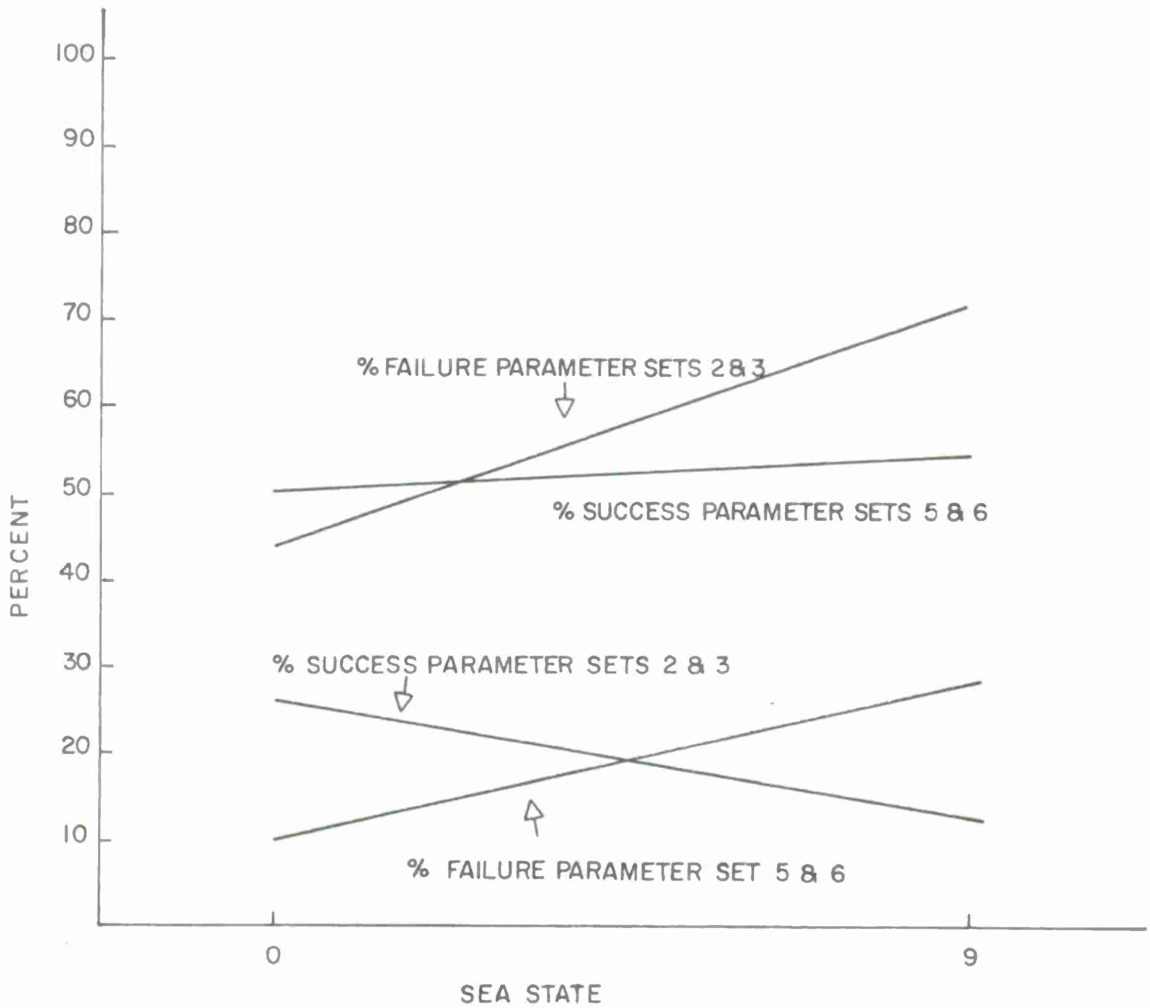

FIGURE 3-10. EVENT SUCCESS AND FAILURE AS A FUNCTION OF SEA STATE.

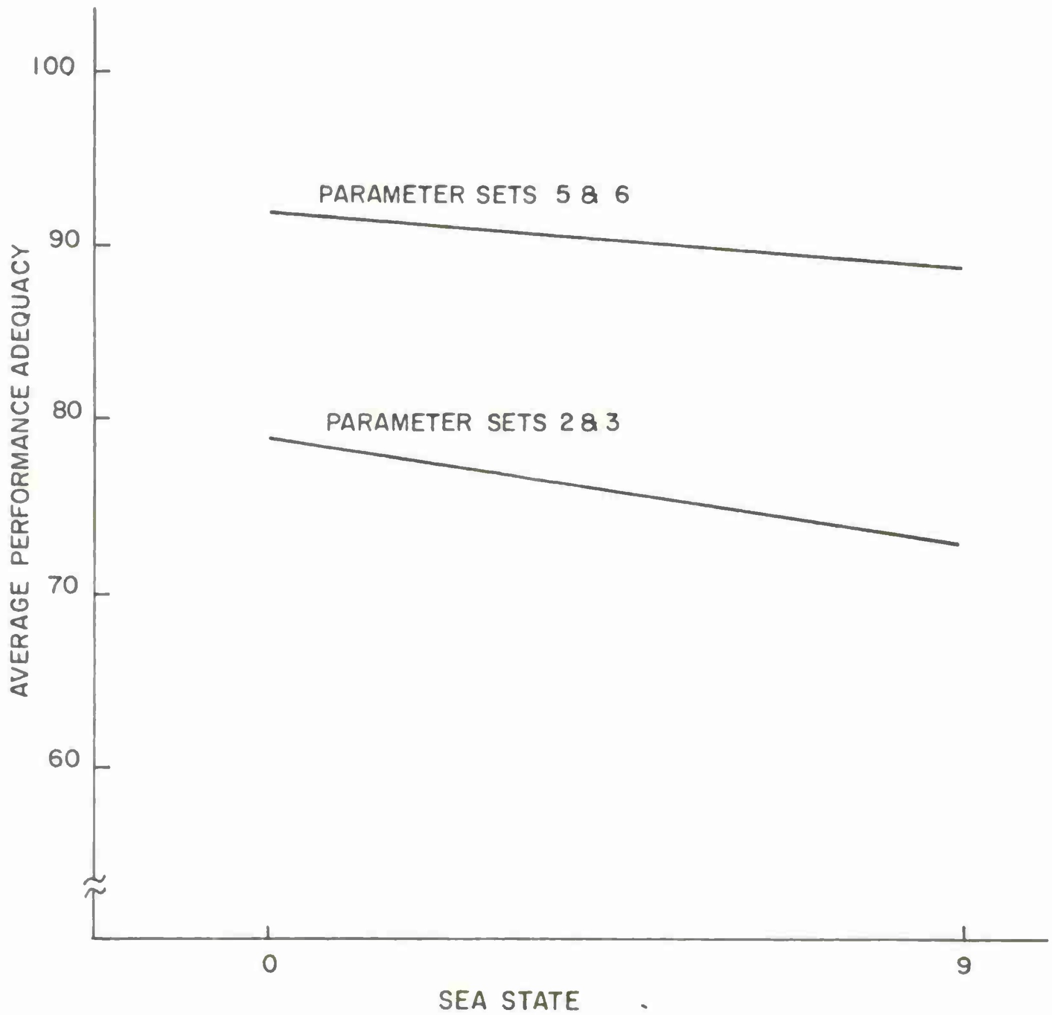

FIGURE 3-11. AVERAGE PERFORMANCE ADEQUACY AS A FUNCTION OF SEA STATE.

Figure 3-11 presents the effects of varying sea state on average performance adequacy (APA). Both parameter sets are in agreement. Each indicates a decrease in APA with increasing weather turbulence. Also, as predicted, the better crew (higher proficiency) of parameter sets 5 and 6 demonstrated higher APA. In summary, it appears from the average failure difference, percentage success/failure, and average performance acequacy data that the model yields results which are directionally sensitive in the anticipated direction when the new sea state variable is implemented--at least over the ranges tested.

Workday Length and Proficiency

One of the many uses of the model can be phrased symbolically as:

$$A \cap B \simeq C \cap D$$

That is, the occurrence of conditions A and B is approximately equivalent (in terms of some criterion such as number of successful event) to conditions C and D. An analyst might, for example, be interested in whether a crew of lesser proficiency which is given more time to work would perform as well as a crew of greater proficiency given less time. This type of analysis is illustrated in the sensitivity tests reported here. In this aspect of the sensitivity tests, proficiency and workday length were varied concurrently. Table 3-5 presents the workday length-proficiency parameter combinations investigated.

Parameter sets 2 and 3 include a long worday with a crew of low proficiency, while parameter sets 5 and 6 include a short workday with high proficiency. Comparisons between the results from parameter sets 2 and 5 and between parameter sets 3 and 6, accordingly provide the desired data.

Table 3-5

Workday Length and Proficiency Parameter Values for Parameter Sets 2, 3, 5, and 6

Parameters	Parameter Set: 2 and 3		Parameter Set: 5 and 6	
Workday length (hours)	18		12	
Primary proficiency				
Per cent fully qualified	0		90	
Per cent minimally qualified	10		10	
Per cent unqualified	90		0	
Secondary proficiency				
Per cent fully qualified	0		90	
Per cent minimally qualified	10		10	
Per cent unqualified	90		0	
Sea State	2: 9	3: 0	5: 9	6: 0
Crew size	9	9	9	9

Figures 3-12, 3-13, and 3-14 present the simulation output resulting from the workday length-proficiency variation. The first of these figures indicates an increase in the average physical workload with the shorter workday-higher proficiency. For parameter set 2 in comparison with parameter set 5, as well as for parameter set 3 in comparison with parameter set 6, the increase amounted to better than 25 per cent. It is possible that the faster crew has to work harder during the shorter time period allotted to them to complete the day's work and that their greater proficiency does not offset the necessary increase in physical labor. Parameter sets 3 and 6 indicated a much greater degree of physical load than the paremeter sets 2 and 5. This result probably, as has been noted earlier, reflects the greater number of events ignored under adverse weather conditions.

Figure 3-13 presents the effects on event success and failure percentages as the result of the workday length-proficiency variation. The percentage of event success increased dramatically for the higher proficiency crews. Analogously, percentage of event failure decreased with the increase in proficiency. While the shorter workday would probably have an effect, in and of itself, prior results with an earlier version of this model (Siegel, Wolf, & Cosentino, 1971) suggest that the large variations observed in event success and failure is primarily a function of the variation in proficiency.

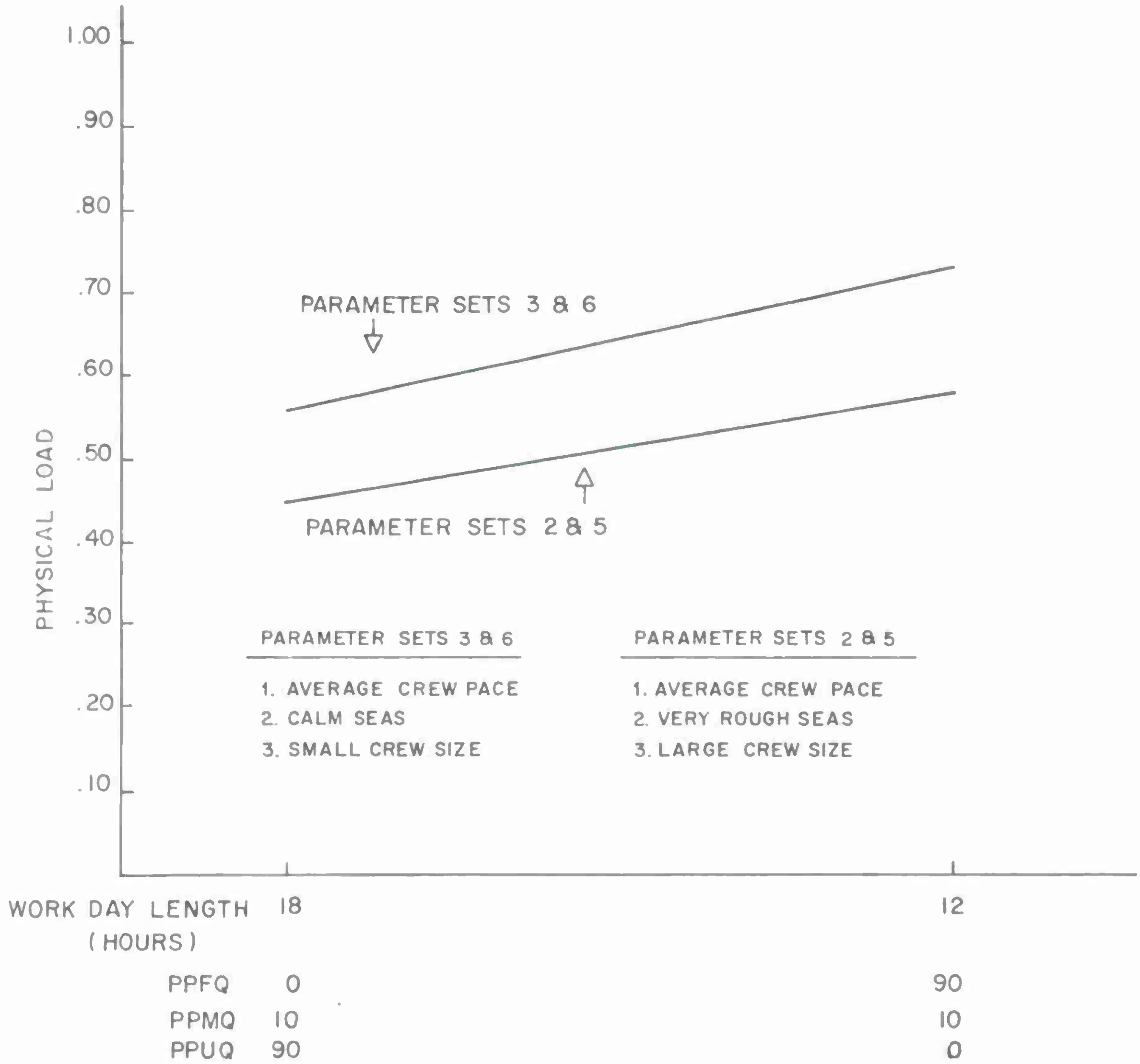

FIGURE 3-12. AVERAGE PHYSICAL LOAD AS A FUNCTION OF WORKDAY LENGTH AND PROFICIENCY

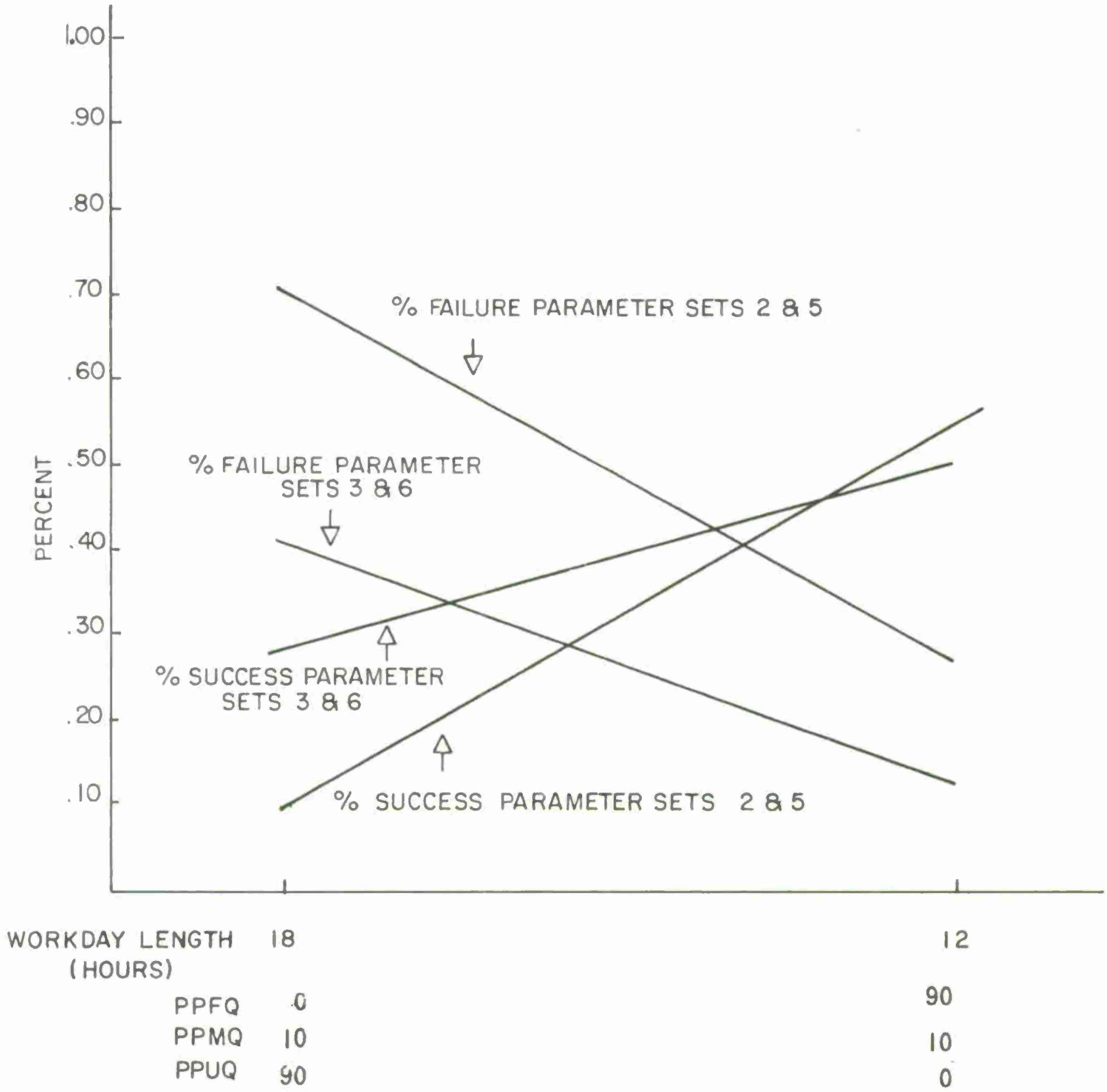

FIGURE 3-13. EVENT SUCCESS AND FAILURE PERCENTAGE AS A FUNCTION OF WORKDAY LENGTH AND PROFICIENCY.

Figure 3-14 presents the effect of varying the workday length and proficiency on average end-of-mission fatigue. No effect is indicated for the comparison of parameter sets 2 and 5. For parameter set 3, compared with parameter set 6, a drop of approximately .07 in fatigue was indicated in the higher proficiency-shorter workday combination. Coupled with the results presented in Figure 3-12, this suggests that while the average physical load may increase because of the shorter workday, the fatigue level at the end of the day has actually been depressed. The higher average fatigue for parameter sets 3 and 6 is, once again, probably reflective of the large number of events ignored during adverse weather conditions.

Integration of results from the three analyses involving comparisons between workday length and crew proficiency combinations suggests support for contentions favoring the trend sensitivity of model parameters to variations in these variables. However, further calibration analysis of the fatigue variable may also be indicated. The data relative to fatigue, event success and failure, and physical workload, for the most part, tend to be logical and consistent with the observed trends being in the predicted directions. These results also serve to demonstrate the utility of the model for assessing the effects of tradeoffs (e. g., low proficiency and a long workday versus high proficiency and a short workday). This type of analysis has traditionally been found to be useful to the system analyst. In the cases shown, the advantage of high proficiency far outweighs the "advantage" of a longer workday.

Average Crew Pace

The effect of varying average crew pace on event success and failure is shown for parameter sets 3 and 7 in Figure 3-15. As would be expected, the percentage of events failed increased, and the percentage of events successfully completed decreased as the average pace of the simulated crews decreased. The percentage of events failed due to this 25 per cent decrease in average crew pace (defined as a slow crew) increased approximately 13 per cent, while the percentage of events successfully completed decreased approximately 8 per cent. These changes in event performance illustrate adequate sensitivity of the model to variations in this variable.

Reliability Analysis

Mean time between failures, mean time to repair, and availability were calculated both for the crew and for the equipment in the simulations involving each parameter set. Additionally, the overall system availability metric, which is a function of both equipment and human reliability, was also calculated after the completion of all the iterations for each run. Equipment mean time between failures (EMTBF), equipment mean time to repair (EMTTR), and equipment availability are calculated within the model in the usual manner. Human mean time between failure (HMTBF) is calculated in terms of touchup and repeat time, while human availability (HAVAIL) is calculated by dividing HMTBF by HMTBF and HMTTR.

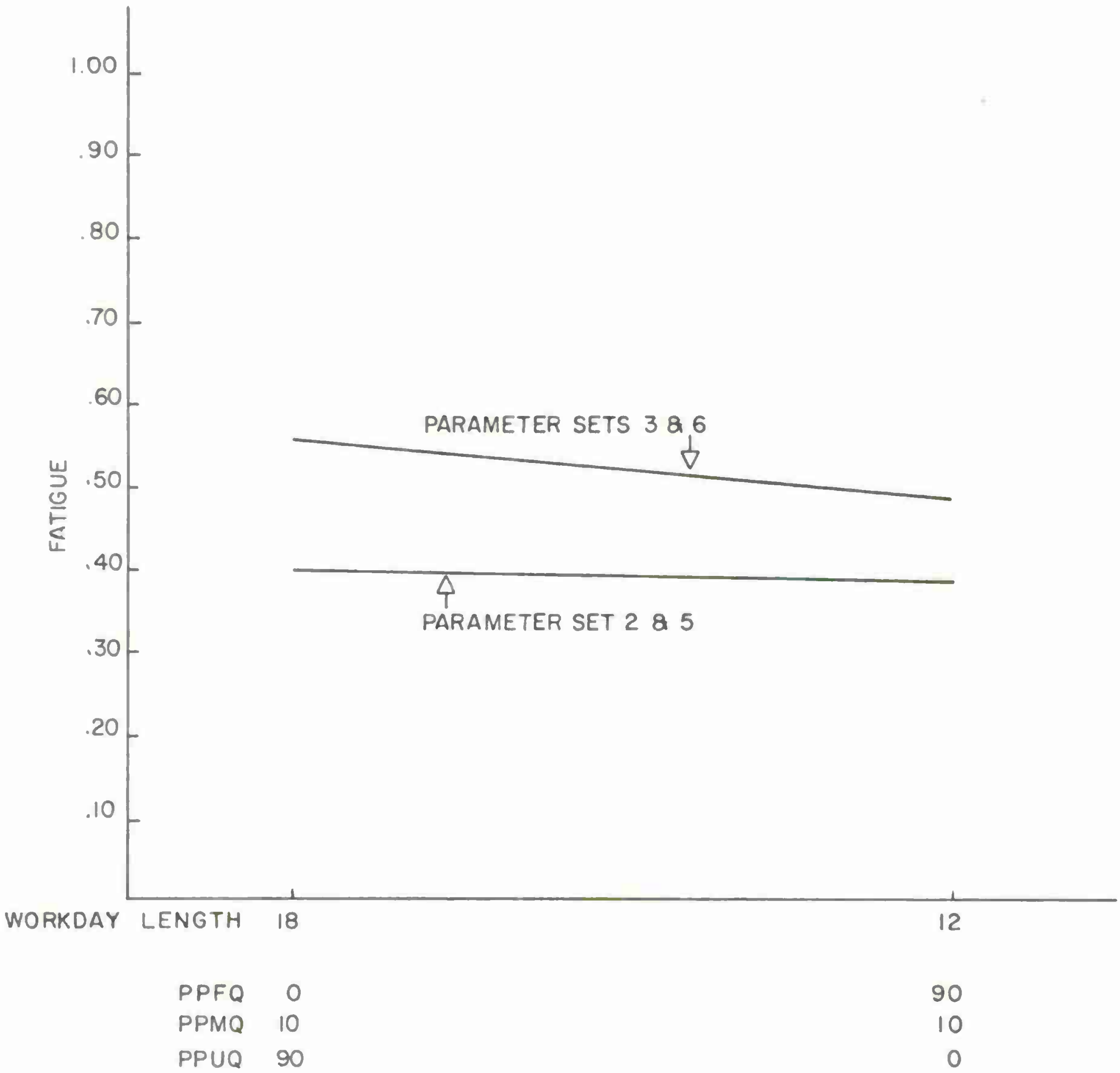

FIGURE 3-14. AVERAGE FATIGUE AS A FUNCTION OF WORKDAY LENGTH AND PROFICIENCY

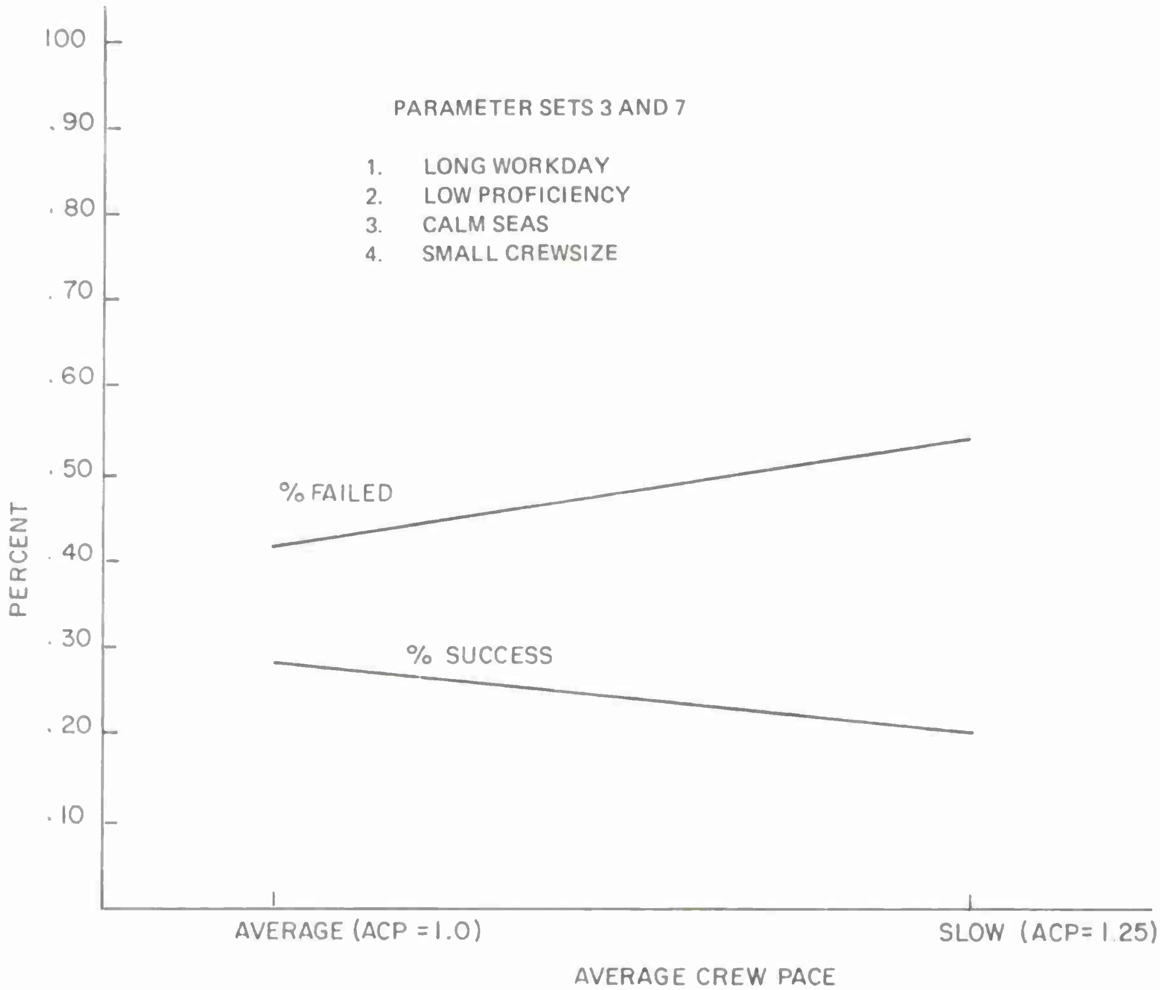

FIGURE 3-15. EVENT SUCCESS AND FAILURE AS A FUNCTION OF AVERAGE CREW PACE

These statistics are particularly sensitive to the number and types of events actually performed during a simulation run. Because of the stochastic nature of the model and the intention of requiring a large number of unscheduled (repair and emergency) events in the sensitivity tests, the actual values of the numerics obtained in this sensitivity analysis are of less concern than relationships between stochastic runs where both a similar number and type of events were performed.

Also, the reliability data reported are only a sample of those actually computed. However, they do reflect the general trends observed. Those analyses which resulted in counter-intuitive findings are currently being investigated.

The present discussion is particularly interested in the human oriented metrics--HMTBF, HMTTR, HAVAIL. The equipment oriented metrics are based on the usual equation and reflect input data.

Parameter sets 2 and 3 differed only in sea conditions. The sea state in parameter sets 2 and 3 was 9 and 0 respectively. Table 3-6 presents the obtained reliability values for these parameter sets.

Table 3-6

Overall Reliability Metrics for Parameter Sets 2 and 3

Parameter Set	MTBF		MTTR		Availability		System Availability
	Human	Equipment	Human	Equipment	Human	Equipment	
2	0.744	3.384	2.71	20.889	0.215	0.139	0.181
3	2.226	3.367	3.06	21.339	0.421	0.136	0.313

The parameter set 2 crew showed shorter HMTBF (as anticipated), shorter HMTTR (against anticipation), lower availability (as anticipated), and lower system availability. The reversal of directional tendency in the case of HMTTR is believed to be an artifact of the low number of iterations included in these sensitivity tests. However, these results may also suggest that further calibration of the HMTTR measure may be necessary.

Table 3-7 presents the various reliability metrics comparing the results from parameter sets 3 and 7. These two parameter sets differed only in the assigned average crew pace. Parameter set 7 represented the slower crew. All the metric comparisons, with the exception of the HMTTR comparison, indicate superiority for the faster crew. There was a considerable increase in system availability as the result of manning the simulated system with a faster crew. However, again there is a reversal for the HMTTR comparison. The present thinking relative to this reversal is the same as that discussed for the prior parameter set comparison.

Table 3-7

Overall Reliability Metrics for Parameter Sets 3 and 7

Parameter Set	MTBF		MTTR		Availability		System Availability
	Human	Equipment	Human	Equipment	Human	Equipment	
3	2.226	3.367	3.06	21.339	0.421	0.136	0.313
7	1.649	3.536	2.86	18.130	0.366	0.163	0.283

The effect of the crew size variable with a short workday, high proficiency crews, average crew pace, and calm seas is shown in Table 3-8. Parameter set 4 includes a crew of 14 men, while parameter set 6 has a smaller crew (9 men).

Table 3-8

Overall Reliability Metrics for Parameter Sets 4 and 6

Parameter Set	MTBF		MTTR		Availability		System Availability
	Human	Equipment	Human	Equipment	Human	Equipment	
4	5.314	2.829	1.88	18.754	0.739	0.131	0.531
6	6.953	3.157	4.60	15.829	0.602	0.166	0.441

The larger crew indicated a shorter HMTBF, a shorter HMTTR, a higher AVAIL, and a higher system availability. Here, all numerics are in the anticipated direction with a 20.4 per cent increase in system availability resulting from the increase in crew size.

In summary, it appears that, as a first attempt at deriving and computing human related reliability and availability metrics, the model has proved successful. The reliability metric values obtained were, by and large, logical and interpretable. There seems to be some need to investigate more fully the HMTTR metric and to confirm that these metrics accurately reflect the logic of the model, as well as the real world situation.

CHAPTER IV

DISCUSSION, SUMMARY, AND CONCLUSIONS

The present study attempted to: (1) extend and strengthen a previously developed model for simulating the acts and behaviors of the operators of an intermediate size system to include a greater number of options to the model user, (2) evolve the model into one which produces reliability oriented metrics for both humans and equipment on both an event and overall system level, and (3) conduct an initial series of sensitivity tests relating the new variables and parameters to those already present in the model. The extensions incorporated as well as the new reliability metrics introduced were reviewed earlier in this report.

The results of the sensitivity tests, taken as a whole, suggest that the logic for the modifications and new variables and parameters as introduced seem to reflect positively on the model's content validity. More specifically, the crew size, sea state, average crew pace, and workday length variables all seemed to respond properly in direction and magnitude in response to the variations introduced. The results of the various reliability calculations also seem promising. However, due to the novelty and uniqueness to this model, it appears that more extensive tests and analysis is required. Real mission data, as opposed to the high equipment failure probability and artificial sequencing of scheduled events employed in the test data set, are required for a more definitive evaluation of these metrics.

Additional calibration and testing of the present model, which represents an adaptation of the Applied Psychological Services' intermediate size crew model (Siegel, Wolf, & Fischl, 1969; Siegel, Wolf, & Cosentino, 1971; Siegel, Lautman, & Wolf, 1972) is currently being performed. However, when one couples the present results with the results of the prior sensitivity tests (Siegel, Wolf, & Cosentino, 1971) and the prior tests of the validity of the model (Siegel, Lautman, & Wolf, 1972), there is considerable basis for believing that a useful method is evolving. We note in this regard that additional efforts which will test further the empirical validity of the present model are anticipated by Applied Psychological Services in the immediate future.

Stochastic vs. Deterministic Predictive Methods

The present approach is based on the belief that human behavior in dynamic social and work situations cannot be represented by deterministic methods. The approach holds that the social and work situations contain considerable random variation and that such variation must be represented in any predictive technique which is concerned with these situations. The logic of the stochastic modeling approach is also based on the contention that direct, unidirectional cause-effect relationships are seldom found in social and work situations. It would be extremely pleasant for the behavioral scientist if such direct relationships existed. Nonetheless, to argue for such relationships is to argue against the whole of individual differences in ability, motivation, and attitudes.

Moreover, models of the type here involved possess certain diagnostic or experimental value. They allow answers to questions like: What would happen if the system is manned in such and such a manner? What would happen if I increased or decreased the length of the workday or the physical workday of the crew? Deterministic methods, by and large, do not allow such experimentation. In this sense, we hold that it is not enough to know that a given system reliability will probably be attained. It is equally important for a technique to provide insight into areas for required remedial action. Otherwise hit and miss methods will be employed. Such methods fail to possess favorable cost/effectiveness due to the time and effort involved in their actuation. They also do not allow the systematic analysis of the complex interactions among subunits which themselves may be nondeterministic.

Summary and Conclusions

This report presented a computer based, stochastic, man-machine simulation model designed to predict and describe the performance of intermediate size crews and to relate that performance to the reliability of both the human and equipment components in the system. The rationale underlying the selection of variables to be simulated, the internal logic of each variable, and the expected interactions were all described. Specific improvements in model capabilities in terms of both increased storage capacities and the introduction of new variables and logic were explicitly detailed and related to the calculation of human, equipment, and system reliability metrics. Flow charts, variable descriptions, and the actual model program (which is currently still being enhanced were also provided.

The sensitivity of the model was also tested and evaluated. Variation in several key variables (such as crew size and workday length) served as the basis for this analysis. The results of the test and analysis suggest that a reasonable start had been made toward the goal of developing a stochastic modeling technique for quantifying reliability and more generally for providing a vehicle for effective system planning relative to a variety of personnel planning situations.

Specific model modifications and improvements which were implemented include, but are not limited to:

- extension of the number of scheduled, repair, and emergency events

- incorporation of the concept of event family for both scheduled and repair events allowing fine grain analysis of event performance data

- introduction of the concept of event type data allowing the analyst almost an unlimited set of parameter values which can be used in any run and which can provide a "bank" of parameter values which can be used for any event

- development of metrics for quantifying reliability for humans and techniques for merging such values with typical equipment reliability data

- inclusion of the option of introducing shifts into the workday

- tracking of consumables on a units level ("spare parts")

Further refinements of the model are necessary and are currently being implemented. These will improve the model's fidelity to real life events and its internal consistency. Validation studies are also required. These are also planned in the immediate future. Nonetheless, the use of the model has been demonstrated and the model can be expected to be of utility to the system analyst both in the design and test of new systems, as well as in analysis of systems currently in operation.

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APPENDIX A

FORTRAN Codes and Definitions

FORTRAN	Description
AASP	Average aspiration
ACP	Average crew pace
ADUR	Average duration of scheduled event
ADURIO	Internal variable
APST	Average psychological stress threshold
ART	Average repair time
ASD	Average standard deviation of repair
ASDE	Average standard deviation of emergency
BE	Effectivity of stress
CALRY	Number of calories required by average crewman per day
CN	Catnap length
DI	Aplhanumeric descriptor array
DTBE	Duration time between emergencies
DTE	Duration time of emergencies
DTR	Duration time of repairs
DUMY	Internal variable
EDCV	Data change value
EMREVT	Emergency event data set
EQREVT	Repair event data set
FP1	Internal variable
FP2	Internal variable
FP3	Internal variable
FP4	Internal variable
FP5	Internal variable
GBG	Internal variable
I	Internal variable
ICLASS	Class
IDES	Description array
IDF	Day number of next failure for each piece of equipment
IDS	Number of duty shifts
IEC	Expected energy consumption
IECE	Expected energy consumption for emergency
IEDC	Data change variable
IEFN	Family number
IEFNX	Temporary variable
IERR	Error branch
IESS	Essentiality

FORTRAN	Description
IESSE	Emergency essentiality
IET	Essentiality threshold
IETYP	Event type number
IFOI	Event number in family
IGRG	Internal array
IH	Event hazard class
IHE	Event hazard class (emergency)
II	Index variable
IND	Printout option indicator array
INT	Event code
IP1	Internal variable
IP2	Internal variable
IP3	Internal variable
IP4	Internal variable
IP5	Internal variable
IPE	Prerequisite event
IQR	Equipment list
IRC	Consumable rate of expenditure (units/hours)
IRC1	Consumable rate of expenditure (units)
IRCE	Consumable rate of expenditure (units/hours)--emergencies
IRCE1	Consumable rate of expenditure (units)--emergencies
IRE	Number of repair events
IREX	Repair event number maximum
ITEM	Temporary variable
ITER	Iteration number
J	Index variable
JJ	Index variable
K	Type of emergency
K1	Physical capacitation fraction
K7	Derating constant
KASE	Case number
KE	Event end type
KK	Index variable
KON	Initial level of consumables (units/hours)
KON1	Initial level of consumables (units)
KONT	Threshold consumables (units/hours)

FORTRAN	Description
KONT1	Threshold consumables (units)
LODM	Mental load
LODME	Mental load for emergency
MAXSL	Maximum sleep
MEN	Crew composition array
MM	Internal variable
MPI	Average number of man days per incidence of physical incapacitation
N	Number of iterations
ND	Number of days
NDBE	Number of days between emergencies
NDMAX	Maximum number of days
NDS	Duty shift
NEME	Number of emergencies
NEQRE	Number of equipments required
NFP1	Internal variable
NFP2	Internal variable
NFP3	Internal variable
NFP4	Internal variable
NFP5	Internal variable
NIF	Number of family
NIP1	Internal variable
NIP2	Internal variable
NIP3	Internal variable
NIP4	Internal variable
NIP5	Internal variable
NIQR	Equipment used array
NOSE	Number of scheduled events
NREQ	Number of men required by type
NREQE	Number of men required by type for emergency
NTYPES	Number of types
NX	Next event number for each alternative
PARAM	Common block
PERSNL	Common block
PID	Average duration of physical incapacity
PPFQ	Per cent fully qualified in primary specialty
PPMQ	Per cent moderately qualified in primary specialty
PPUQ	Per cent unqualified in primary specialty

FORTRAN	Description
PRB	Probability of each alternative path
PTT	Cross training probability table
PTTT	Common block
PWRRT	Average short term power output
RELH	Equipment reliability
RELI	Intermittent reliability
RTU	Repair touchup code
SCHEVT	Internal variable
SESTA	Sea state
SIGWT	Standard deviation of body weight
SLEEP	Number of hours since last eight hour sleep period
SPFQ	Per cent fully qualified in secondary specialty
SPMQ	Per cent minimally qualified in secondary specialty
SPUQ	Per cent unqualified in secondary specialty
ST	Earliest starting time allowed
TFAT	Fatigue threshold
TL	Time limit by which event must be completed
TS	Consumable threshold set identifier (units/hours)
TS1	Consumable threshold set identifier (units)
TSE	Threshold set for consumables below which event is ignored (units/hours)
TSE1	Threshold set for consumables below which event is ignored (units)
TSR	Threshold set for consumables below which emergency is ignored (units/hours)
TSR1	Threshold set for consumables below which emergency is ignored (units)
TUI	Intermittent reliability
TYPE	Internal variable
WORK1	Number of hours worked after which no new work assignment is made
WORK2	Number of hours worked after which no new work is authorized
WT	Mean body weight
ZPC	Physical capability constant

Main Program

FORTRAN	Description
AASP	Average aspiration
ABS	Absolute value
ACAL	Calories expended since last slept for each man in crew
ACP	Average crew pace
ADUR	Average duration of scheduled event (hours)
ADUR2	One half of average duration
ADUR10	Average duration of scheduled event in type data
AEPL	Average equipment performance level
AMAX1	Maximum value
AMIN1	Minimum value
APA	Average performance adequacy
APST	Average psychological stress threshold
APW	Average physical workload for the day for each man in crew
ART	Average repair time
ASD	Standard deviation of ADUR
ASDE	Average standard deviation (emergency)
ASP	Level of aspiration at beginning of iteration for each man in crew
ATEM	Temporary variable
BE	Effectivity stress on performance on a no-stress state
BLANK	Temporary variable
BTEM	Temporary variable
CAL	Average calories expended per day for each man in crew
CALR	Intermediate calculation used in crew selection process
CALRY	Number of calories required by average crewman per day
CART	Current average repair time
CASP	Current level of aspiration for each man in crew
CCAL	Calories expended for the event for each man in crew
CCC	Current crew competence
CCI	Initial crew competence
CDT	Current downtime
CML	Crew mental load
CMLMX	Maximum crew mental load obtained for an event during the day
CN	Catnap length. Below considered rest. Above is sleep.
CTEM	Temporary variable
CUT	Current uptime
DI	Alphanumeric descriptor array
DS	Amount of sleep for the day for each man in crew
DTBE	Duration time between emergencies

FORTRAN	Description
DTE	Duration time of emergencies
DTEM	Temporary variable
DTR	Duration time of repair
EA	Goodness of aspiration value
EC	Goodness of competence value
EDCV	Data change value
EF	Goodness of physical capability value
EH	Event hazard
EMTBF	Equipment meantime between failures
EMTTR	Equipment meantime to repair
EPEFF	Equipment performance effectiveness
EPL	Equipment performance level
ES	Goodness of stress value
ESSS	Temporary variable
ETEM	Temporary variable
EXER	Overexertion factor used in physical capability calculation
FAT	Fatigue level for each man in crew
FDIFF	Failure difference
FLIC	Number of men in crew
FLIG	Number of crew members in group participation in current event
FLOAT	Conversion to real
FUNC	Function
GASP	Group aspiration level
GPACE	Group pace value used in performance time calculation
GPCC	Group physical capability
GPERF	Group performance
GSTR	Group stress
GSTRM	Group stress threshold
HEADR	Program header
HR	Hazard ratio used in SI calculations
HRSE	Total man hours worked on emergency events for the day
HRSR	Total man hours worked on repair events for the day
HRSS	Total man hours worked on scheduled events for the day
HSLS	Number of hours since last slept for each man in crew
I	Index variable
IAA	Number of men in crew for each echelon
IABC	Temporary variable
IC	Maximum number of crewmen

Main Program

FORTRAN	Description
ICE	Command echelon for each crewman
ICLASS	Class
ICML	Event with maximum CML for the day
ICSS	Current sea state
IDC	Calories expended for the day for each crewman
IDCMX	Event with maximum calories expended for the day
IDE	Day number of next occurrence for each emergency event
IDF	Day number of next failure for each piece of equipment
IDS	Number of duty shifts
IE	Event number
IEC	Expected energy consumption during event (calories per hour)
IECE	Expected energy consumption during emergency event (calories per hour)
IEDC	Data change variable
IEFN	Family number
IEIE	Counter for number of different events attempted for the day
IEMAX	Maximum number of events
IESS	Event essentiality
IESSE	Emergency event essentiality
IET	Essentiality threshold. Determines ignores.
IETYP	Event type number
IEVENT	Event to be simulated for the day
IFIRST	Temporary variable
IFOI	Event number in family code
IG	Group member
IGAP	Internal variable
IGIND	Indicator for cause of ignored event
IGNOR	Indicator for ignored event (1= event ignored)
IH	Event hazard class (1-3= low, 4-6= medium, 7-9= heavy)
IHE	Event hazard class (emergency)
II	Index variable
III	Index variable
IIIP1	Index variable
IND	Indicators for output recording options
INIF	Internal variable
INIQ	Internal variable
INT	Event code (1= normal, 2= training)
INVS	Inverse pointer array
IOIF	Operator induced failure

FORTRAN	Description
IPE	Prerequisite event
IPET	Previous event indicator
IPI	Incomplete processing indicator
IPS	Primary specialty for each crewman
IPSS	First 20 slots same as IPS, second 20 slots same as ISS
IPTR	Pointer array for events
IQMAX	Maximum number of pieces of equipment or repair events
IQR	Equipment list
IRC	Consumable rate of expenditure (units/hours)
IRC1	Consumable rate of expenditure (units)
IRCE	Consumable rate of expenditure for emergencies (units/hours)
IRCE1	Consumable rate of expenditure for emergencies (units)
IRE	Number of repair events
ISIE	Internal variable
ISS	Secondary specialty for each man in crew
IST	Internal variable
ISW1	Internal variable
ITAP	Tape option
ITEM	Temporary variable
ITER	Current interaction
ITRY	Counter for number of attempts with current event
ITYPE	Type for which man was selected for event for each man in group
J	Internal variable
JI	Internal variable
JJ	Internal variable
JNDS	Internal variable
K	Type of emergency
K1	Fraction to which a man's physical capability is reduced
K7	Derating constant for acceptable performance
KA	Number of crew members available for selection for current event
KASE	Case number
KE	Event end time type (1= fixed end, 2= variable end)
KIND	Indicator in group selection process (0= searching primary specialties, 1=secondary
KK	Internal variable
KMAX	Maximum number of types of emergency events
KON	Initial level of consumable (units/hours)
KON1	Initial level of consumable (units)

FORTRAN	Description
KONC	Current consumable level foreach consumable (units/hours)
KONC1	Current consumable level for each consuamble (units)
KONE	Consumables expended for the event for each man in group
KONE1	Consumables expended (units)
KONT	Consumable threshold (units/hours)
KONT1	Consumable threshold (units)
KOUNT	Internal variable
KTEMP	Temporary variable
LI	Crewman chosen as leader for this event
LL	Internal variable
LMAX	Maximum number of consumables (units/hours)
LMAX1	Maximum number of spare parts consumables (units)
LODM	Event mental load (1-3 light, 406 medium, 7-9 heavy)
LODME	Mental load (emergencies)
LSHIFT	Internal variable
M	Crewman number
MA	Man selected for the event by type
MAT	Man selected for the event
MAVAIL	Man selected for the event
MAXSL	Maximum sleep permitted per day (hour)
MAXST	Maximum stress obtained for any event during the day
MAXSTE	Event on which maximum stress was obtained
MCHSN	Indicator for man selected for the event (0= not selected; 1= selected
MEN	Crew composition, number of men of each type by crew selection
MPCC	Maximum physical capability for the day for each man in crew
MPI	Average number of man days per indices of physical incapacitation
N	Number of mission iterations per computer run
ND	Number of days, current number
NDAYS	Total number of days in the simulation (updated after each iteration completed)
NDBE	Number of days between emergencies
NDMAX	Maximum number of days
NDS	Duty shifts
NE	Number of emergency events to be simulated this day
NEME	Temporary variable
NEQRE	Number of equipments (emergencies)
NFALE	Number of failures for this day
NIF	Number in family
NIGNR	Number of ignored events for this day
NIQR	Number of equipments in repair
NKASES	Number of cases

FORTRAN	Description
NN	Temporary variable
NOFAIL	Number of failures for iteration for each crewman
NOIF	Number of operator induced failures (counter)
NOIFT	Total number of operator induced failures
NOSE	Number of scheduled events
NOSE1	Temporary variable
NOSUC	Number of successes for iteration for each man in crew
NPI	Number of crewmen to be incapacitated this day
NPRFM	Number of events performed
NPTR	Pointer array if in event sequencing
NR	Repair number, number of repair events to be simulated this day
NREPT	Number of events repeated this day
NREQ	Number of men of each type required by event
NREQE	Number of men of each type required for an emergency
NREQT	Number of men required for the event for each type
NS	Sickness indicator for each man in crew (0= well, 1= sick)
NSUC1	Number of successes on the first try this day
NSUC2	Number of successes on the second try this day
NTE	Number of different events to be simulated this day
NTMAX	Maximum number of types of personnel
NU	Number of successes for the day for each crewman
NUMFAM	Number of families
NX	Next event number for each alternative
PA	Performance adequacy
PACE	Working pace for each man in crew
PAF	Pace adjustment factor used in calculations GPACE
PC	Physical capability at iteration start for each crewman
PCC	Current physical capability for each crewman
PCDUM	Equipment to PPFQ, PPMQ, PPU, SPFQ, SPMQ, SPUQ
PCOM	Primary competence for each crewman
PEA	Temporary variable
PEFF	Performance effectiveness
PERF	Performance level for each crewman
PI	Physical incapacity for each crewman
PI2	Number of future days of physical incapacity for each crewman
PID	Average duration of physical incapacity (days)
PPFQ	Per cent of crew fully qualified in primary specialty
PPMQ	Per cent of crew minimally qualified in primary specialty
PPUQ	Per cent of crew unqualified in primary specialty

FORTRAN	Description
PRB	Probability of each alternative path after current event
PSCOM	PCOM (1-20) and SCOM (1-20)
PSESIC	Per cent seasick
PT	Performance time for each event
PTR	Sequential order of events for the day
PTT	Cross training probability table. Given primary by secondary
PWR	Average short term power output rate for each crewman
PWRRT	Average short term power output rate for average crewman (calories/hour)
RELH	Equipment reliability
RELI	Intermittent reliability
RTEMP	Temporary variable
RTU	Action if event performance is unsatisfactory (1= repeat, 2= touchup, 3= no action)
RY2	Action number from uniform distribution
SCOM	Secondary competence for each man in crew
SEF	Efficiency factor
SESTA	Sea state
SF	Slowness factor used in computing GPACE
SFDIFF	Failure difference
SFTHRS	Shift hours
SGEM	System general effectiveness measure
SI	Safety index
SIDC	Total calories expended this event
SIDCMX	Maximum SIDC for any event this day
SIGWT	Standard deviation of work time
SLEEP	Number of hours since last 8 hour sleep period
SPFQ	Per cent of crew fully qualified by average crewman at mission start
SPL	System performance level
SPMQ	Per cent of crew minimally qualified in secondary specialty
SPUQ	Per cent of crew unqualified in secondary specialty
SRL	System reliability level
ST	Earliest starting time allowed (hours)
STAR	Star
STRM	Psychological stress for each crewman
SUCC	Evaluation indicator (S= successful, U= otherwise)
TAVAIL	Testing criterion for each man eligible for the event
TEH	Total event hazard for the day
TEM1	Temporary variable
TEM2	Temporary variable
TEM3	Temporary variable

FORTRAN	Description
TEMP	Temporary variable
TFAT	Fatigue threshold below which sleep is not authorized
THW	Total hours worked for the crew for the day
TITLE	Program title
TL	Time limit by which event must be completed (hours)
TPCOM	Temporary primary competence
TPSCOM	Temporary/secondary competence array
TS	Consumable threshold set identifier (units/hour)
TS1	Consumable threshold set identifier (units)
TSCOM	Temporary secondary competence
TSE	Consumable threshold for emergencies (units/hours)
TSE1	Consumable threshold emergencies (units)
TUI	Intermittent failure rate
TW	Working time for the day for each crewman
TWP	Working time in primary specialty for each crewman
TWS	Working time in secondary specialty for each crewman
USH	Unmanned station hours for the current event
USHT	Total unmanned station hours for the day
V	Value of time function used in computing performance time
WH	Time since last event participation for each crewman, wait hours
WORK1	Number of hours worked after which no new assignments are made
WORK2	Number of hours worked after which further work is not authorized
WT	Mean body weight of total population (lbs)
YU	Internal variable
Z	Last real time worked this day for each crewman
Z1	Earliest time when all group members are available
Z2	Earliest time current event can begin
ZC	Real time of completion for each event
ZPC	Physical capability constant

IPUYSM Function Subprogram

FORTRAN	Description
IPUYSN	Uniform probability test function
K	Temporary probability variable
PAR	Type of emergency
TEST	Temporary variable
Y	Temporary variable

FBUILD Function Subprogram

FORTRAN	Description
FBUILD	Function sub program
H	Temporary variable
HSLS	Hours since last slept
TEM1	Temporary variable

FORTRAN	Description
AASP	Average aspiration
ACP	Average crew pace
ADALY	Internal array for daily summary
AEPL	Average equipment performance level
APA	Average performance adequacy
APST	Average psychological stress threshold
APW	Average physical workload
ASP	Aspiration
ASPA	Temporary aspiration
BE	Effectivity of stress on performance
CAL	Average calories expended per day for each man in crew
CALRY	Number of calories required by average crewman per day
CART	Current average repair time
CARTI	Internal array for average repair time
CASP	Current aspiration
CCAL	Current calorie level
CDT	Current down time
CDTI	Internal array for downtime
CI	Blanks
CML	Crew mental load
CMLMX	Crew mental load (maximum)
CN	Catnap length
CUT	Current up time
CUTI	Internal array for uptime
DALY	Output array
DI	Alphanumeric decription array
DS	Amount of sleep for the day
EDCV	Data change value
EMTBF	Equipment mean time between failures
EMTTR	Equipment mean time to repair
EPEFF	Equipment performance effectiveness
EPL	Equipment performance level
FAT	Fatigue
FD	Temporary variable
FLIC	Crew size (floating point)
FLITER	Iteration (floating point)
FLOAT	Floating point

FORTRAN	Description
FNTE	Number of total events (floating point)
HRSE	Hours worked on emergency
HRSR	Hours worked on repairs
HRSS	Hours worked on scheduled events
HSLS	Hours since last slept
HSLSA	Reinitialization of hours since last slept
I	Internal variable
IAA	Crew echelon number
IC	Maximum number of crewmen
ICE	Command echelon
ICML	Crew mental load
ICSS	Current sea state
IDALY1	Internal array for daily summary
IDC	Data change
IDCMX	Data change maximum
IEDC	Data change variable
IEFN	Family number
IET	Essentiality threshold
IETYP	Event type number
IFOI	Event number in family code
IITEM	Temporary variable
IMTAB	Output array
IND	Indicators
IPE	Prerequisite event
IPS	Primary specialty
IQMAX	Maximum number of pieces of equipment or repair events
ISS	Secondary specialty for each man in crew
ITER	Iteration
J	Temporary variable
JITEM	Internal array for daily summary
K	Type of emergency

FORTRAN	Description
K1	Fraction to which a man's physical cabality is reduced after daily quota is done
K7	Derating constant for acceptable performance
KK	Internal variable
KON	Initial level of consumable (units/hours)
KON1	Initial level of consumables (units)
KONC	Current consumable level (units/hours)
KONC1	Current consumable level (units)
KONT	Consumable threshold (units/hours)
KONT1	Consumable threshold (units)
MAXSL	Maximum sleep permitted per day
MAXST	Maximum stress for any event
MAXSTE	Event of maximum stress
MPCC	Maximum physical capability
N	Number of iterations
N1S1	Internal variable
ND	Number of days
NDAYS	Days in simulation
NDMAX	Maximum number of days
NE	Number of emergency events
NEME	Temporary variable
NEQRE	Number of equipments emerging
NFALE	Number of failures this day
NIF	Number in family
NIGNR	Number of events ignored
NOSE	Number of scheduled events
NPRFM	Number of events performed
NR	Number of repairs
NREI	Total repairs for the run
NREPT	Number of repeats
NSUC1	Number of successes in first try
NSUC2	Number of successes in second try

FORTRAN	Description
NTE	Total number of events
NTIPE	Number of men in each type
NU	Number of daily successes by crewman
NX	Next event number for each alternative
OUTA	Internal array
OUTB	Output array
PACE	Working pace
PACEA	Reinitialization of work pace
PC	Physical capability
PCA	Reinitialization of physical capability
PCC	Current physical capability
PCOM	Primary competence
PCOMA	Reinitialization of primary competence
PEFF	Performance effectiveness
PERF	Performance level by crewman
PI	Physical incapability
PI2	Number of future days of physical incapacity for each crewman
PIA	Reinitialization of physical capacity by crewman
PRB	Probability for each alternative path after current event
PWR	Average short term power output by crewman
PWRRI	Average short term power output for average crewman
RELI	Intermittent reliability
REMTB	Temporary variable for equipment mean time between failure
REMTR	Temporary variable for equipment mean time to repair
RTU	Action if event performance is unsatisfactory
SCOM	Secondary competence
SCOMA	Secondary competence reinitialized
SESTA	Sea state
SFDIFF	Failure difference
SGEM	General system measure
SI	Safety index
SIDCMX	Maximum calories expended for this event
SLEEP	Number of hours since last 8 hour sleep period
SPL	System performance level

FORTRAN	Description
SRL	System reliability level
ST	Earliest starting time allowed (hours)
STRM	Stress threshold
T3	Temporary variable
TDALY	Daily total output array
TEH	Total daily event hazard
TEM1	Temporary variable
TEM3	Temporary variable
TFAT	Fatigue threshold
TIITER	Iteration summary array
TL	Time limit by which event must be completed (hours)
TOT	Internal variable
TOUTA	Internal array
TPCOM	Temporary primary competence
TS	Consumable threshold set identification (units/hours)
TS1	Consumable threshold set identifier (units)
TSCOM	Temporary secondary competence
TW	Time worked
TWP	Time worked in primary
TWS	Time worked in secondary
USHT	Unmanned station hours
WORK1	Number of hours worked after which no new assessment is made
WORK2	Number of hours worked after which further work is not authorized
ZTEM	Temporary variable

APPENDIX B

Input Data Formats

APPENDIX B

INPUT DATA FORMATS

Title Cards

Description		FORTRAN	Format	Value
Card 1	Number of iterations	NKASES	I3	__ __ __
Card 2	Title	HEADR	12A6	72 spaces
Card 3	Tape input option	ITAP	I3	__ __ __
	Number of days simulated	NDMAX	I3	__ __ __

Parameter Names	*FORTRAN*	*Value*
		$PARAM
(card 4 and on)		*NFP2/FP2=*
Average psychological stress threshold	APST	_______,
Hours worked after which no new assignments are made	WORK 1	_______,
Hours worked after which further work is unauthorized	WORK 2	_______,
Hours since last sleep period by average crew member at start of mission	SLEEP	_______,
Catnap length-hours below which is rest, and above which is sleep	CN	_______,
Maximum sleep permitted per day (hours)	MAXSL	_______,
Fatigue threshold-below which sleep is not authorized	TFAT	_______,
Average crew space	ACP	_______,
Number of calories required by average crew member per day	CALRY	_______,
Average short term power output for average crew member (calories/hour)	PWRRT	_______,
Derating constant for acceptable performance	K7	_______,
Fraction to which man's physical capability reduced when daily quota done	K1	_______,
Effect of stress on performance	BE	_______,
Initial aspiration level	AASP	_______,
Initial value of consumable: 1 ____________	KON(1)	_______,
(units/hour) 2 ____________	KON(2)	_______,
3 ____________	KON(3)	_______,
4 ____________	KON(4)	_______,
5 ____________	KON(5)	_______,
6 ____________	KON(6)	_______,
7 ____________	KON(7)	_______,
8 ____________	KON(8)	_______,
9 ____________	KON(9)	_______,
10 ____________	KON(10)	_______,

Title Cards Description	FORTRAN	VALUE
Consumable threshold for consumable 1, threshold 1	KONT(1,1)	________,
2	KONT(2,1)	________,
3	Kont(3,1)	________,
4	KONT(4,1)	________,
5	KONT(5,1)	________,
6	KONT(6,1)	________,
7	KONT(7,1)	________,
8	KONT(8,1)	________,
9	KONT(9,1)	________,
10	KONT(10,1)	________,
consumable 1, threshold 2	KONT(1,2)	________,
2	KONT(2,2)	________,
3	KONT(3,2)	________,
4	KONT(4,2)	________,
5	KONT(5,2)	________,
6	KONT(6,2)	________,
7	KONT(7,2)	________,
8	KONT(8,2)	________,
9	KONT(9,2)	________,
10	KONT(10,2)	________,
consumable 1, threshold 3	KONT(1,3)	________,
2	KONT(2,3)	________,
3	KONT(3,3)	________,
4	KONT(4,3)	________,
5	KONT(5,3)	________,
6	KONT(6,3)	________,
7	KONT(7,3)	________,
8	KONT(8,3)	________,
9	KONT(9,3)	________,
10	KONT(10,3)	________,
consumable 1, threshold 4	KONT(1,4)	________,
2	KONT(2,4)	________,
3	KONT(3,4)	________,
4	KONT(4,4)	________,
5	KONT(5,4)	________,
6	KONT(6,4)	________,
7	KONT(7,4)	________,
8	KONT(8,4)	________,
9	KONT(9,4)	________,
10	KONT(10,4)	________,
consumable 1, threshold 5	KONT(1,5)	________,
2	KONT(2,5)	________,
3	KONT(3,5)	________,
4	KONT(4,5)	________,
5	KONT(5,5)	________,
6	KONT(6,5)	________,
7	KONT(7,5)	________,
8	KONT(8,5)	________,
9	KONT(9,5)	________,
10	KONT(10,5)	________,

Title Cards Description	FORTRAN	VALUE
Consumable threshold for consumable 1, threshold 6	KONT(1,6)	________,
2	KONT(2,6)	________,
3	KONT(3,6)	________,
4	KONT(4,6)	________,
5	KONT(5,6)	________,
6	KONT(6,6)	________,
7	KONT(7,6)	________,
8	KONT(8,6)	________,
9	KONT(9,6)	________,
10	KONT(10,6)	________,
consumable 1, threshold 7	KONT(1,7)	________,
2	KONT(2,7)	________,
3	KONT(3,7)	________,
4	KONT(4,7)	________,
5	KONT(5,7)	________,
6	KONT(6,7)	________,
7	KONT(7,7)	________,
8	KONT(8,7)	________,
9	KONT(9,7)	________,
10	KONT(10,7)	________,
consumable 1, threshold 8	KONT(1,8)	________,
2	KONT(2,8)	________,
3	KONT(3,8)	________,
4	KONT(4,8)	________,
5	KONT(5,8)	________,
6	KONT(6,8)	________,
7	KONT(7,8)	________,
8	KONT(8,8)	________,
9	KONT(9,8)	________,
10	KONT(10,8)	________,
consumable 1, threshold 9	KONT(1,9)	________,
2	KONT(2,9)	________,
3	KONT(3,9)	________,
4	KONT(4,9)	________,
5	KONT(5,9)	________,
6	KONT(6,9)	________,
7	KONT(7,9)	________,
8	KONT(8,9)	________,
9	KONT(9,9)	________,
10	KONT(10,9)	________,
consumable 1, threshold 10	KONT(1,10)	________,
2	KONT(2,10)	________,
3	KONT(3,10)	________,
4	KONT(4,10)	________,
5	KONT(5,10)	________,
6	KONT(6,10)	________,
7	KONT(7,10)	________,
8	KONT(8,10)	________,
9	KONT(9,10)	________,
10	KONT(10,10)	________,

Title Cards Description		FORTRAN	VALUE
Initial value of consumable: (units)	1 ______	KON1(1)	______,
	2 ______	KON1(2)	______,
	3 ______	KON1(3)	______,
	4 ______	KON1(4)	______,
	5 ______	KON1(5)	______,
	6 ______	KON1(6)	______,
	7 ______	KON1(7)	______,
	8 ______	KON1(8)	______,
	9 ______	KON1(9)	______,
	10 ______	KON1(10)	______,
Consumable threshold for consumable	1, threshold 1	KONT1(1)	______,
	2	KONT1(2)	______,
	3	KONT1(3)	______,
	4	KONT1(4)	______,
	5	KONT1(5)	______,
	6	KONT1(6)	______,
	7	KONT1(7)	______,
	8	KONT1(8)	______,
	9	KONT1(9)	______,
	10	KONT1(10)	______,
consumable	1, threshold 2	KONT1(1,2)	______,
	2	KONT1(1,2)	______,
	3	KONT1(3,2)	______,
	4	KONT1(4,2)	______,
	5	KONT1(5,2)	______,
	6	KONT1(6,2)	______,
	7	KONT1(7,2)	______,
	8	KONT1(8,2)	______,
	9	KONT1(9,2)	______,
	10	KONT1(10,2)	______,
consumable	1, threshold 3	KONT1(1,3)	______,
	2	KONT1(2,3)	______,
	3	KONT1(3,3)	______,
	4	KONT1(4,3)	______,
	5	KONT1(5,3)	______,
	6	KONT1(6,3)	______,
	7	KONT1(7,3)	______,
	8	KONT1(8,3)	______,
	9	KONT1(9,3)	______,
	10	KONT1(10,3)	______,
consumable	1, threshold 4	KONT1(1,4)	______,
	2	KONT1(2,4)	______,
	3	KONT1(3,4)	______,
	4	KONT1(4,4)	______,
	5	KONT1(5,4)	______,
	6	KONT1(6,4)	______,
	7	KONT1(7,4)	______,
	8	KONT1(8,4)	______,
	9	KONT1(9,4)	______,
	10	KONT1(10,4)	______,

Title Cards

Description	FORTRAN	VALUE
Consumable threshold for consumable 1, threshold 5	KONT1(1,5)	______,
2	KONT1(2,5)	______,
3	KONT1(3,5)	______,
4	KONT1(4,5)	______,
5	KONT1(5,5)	______,
6	KONT1(6,5)	______,
7	KONT1(7,5)	______,
8	KONT1(8,5)	______,
9	KONT1(9,5)	______,
10	KONT1(10,5)	______,
consumable 1, threshold 6	KONT1(1,6)	______,
2	KONT1(2,6)	______,
3	KONT1(3,6)	______,
4	KONT1(4,6)	______,
5	KONT1(5,6)	______,
6	KONT1(6,6)	______,
7	KONT1(7,6)	______,
8	KONT1(8,6)	______,
9	KONT1(9,6)	______,
10	KONT1(10,6)	______,
consumable 1, threshold 7	KONT1(1,7)	______,
2	KONT1(2,7)	______,
3	KONT1(3,7)	______,
4	KONT1(4,7)	______,
5	KONT1(5,7)	______,
6	KONT1(6,7)	______,
7	KONT1(7,7)	______,
8	KONT1(8,7)	______,
9	KONT1(9,7)	______,
10	KONT1(10,7)	______,
consumable 1, threshold 8	KONT1(1,8)	______,
2	KONT1(2,8)	______,
3	KONT1(3,8)	______,
4	KONT1(4,8)	______,
5	KONT1(5,8)	______,
6	KONT1(6,8)	______,
7	KONT1(7,8)	______,
8	KONT1(8,8)	______,
9	KONT1(9,8)	______,
10	KONT1(10,8)	______,
consumable 1, threshold 9	KONT1(1,9))	______,
2	KONT1(2,9)	______,
3	KONT1(3,9)	______,
4	KONT1(4,9)	______,
5	KONT1(5,9)	______,
6	KONT1(6,9)	______,
7	KONT1(7,9)	______,
8	KONT1(8,9)	______,
9	KONT1(9,9)	______,
10	KONT1(10,9)	______,

Title Cards

Description	FORTRAN	VALUE
Consumable threshold for consumable 1, threshold 10	KONT1(1,10)	______,
2	KONT1(2,10)	______,
3	KONT1(3,10)	______,
4	KONT1(4,10)	______,
5	KONT1(5,10)	______,
6	KONT1(6,10)	______,
7	KONT1(7,10)	______,
8	KONT1(8,10)	______,
9	KONT1(9,10)	______,
10	KONT1(10,10)	______,
Sea State		
(term and height of waves in feet) 0 -- calm, glassy	SESTA(1)	______,
1 -- rippled, 0-1	SESTA(2)	______,
2 -- smooth, 1-2	SESTA(3)	______,
3 -- slight, 2-4	SESTA(4)	______,
4 -- moderate, 4-8	SESTA(5)	______,
5 -- rough, 8-13	SESTA(6)	______,
6 -- very rough, 13-20	SESTA(7)	______,
7 -- high, 20-30	SESTA(8)	______,
8 -- very high, 30-45	SESTA(9)	______,
9 -- phenomenal, over 45	SESTA(10)	1.0,
Intermittent reliability--electronic equipment	RELI(1)	______,
Intermittent reliability--electrical equipment	RELI(2)	______,
Intermittent reliability--electromechanical equipment	RELI(3)	______,
Intermittent reliability--mechanical equipment	RELI(4)	______,
Number of mission iterations		*NIP2/IP2=*
Number of iterations per computer run	N	______,
Essentiality threshold, below which an event is ignored (1-100)	IET	______,
Indicators for output recording options	IND(1)	_,
Print all inputs (1), or parameters only (0)	IND(2)	_,
Print (1), or don't print (0): crew initial conditions	IND(3)	_,
: day numbers of 1st. repair, emergencies	IND(4)	_,
Print detailed event results for all events beginning with day	IND(5)	_,
Print end of day results for all days beginning with day	IND(6)	_,
Print (1), or don't print (0) mission results by individual man	IND(7)	_$

Title Cards Description	FORTRAN	VALUE
		$PERSNL
		NFP1/FP1
Mean body weight of total population	WT	____,
Standard deviation of population body weight	SIGWT	____,
%crew fully qualified in prime specialty	PPFQ	____,
%crew minimally qualified in prime specialty	PPMQ	____,
%crew unqualified in prime specialty	PPUQ	____,
%crew fully qualified in second specialty	SPFQ	____,
%crew minimally qualified in second specialty	SPMQ	____,
%crew unqualified in second specialty	SPUQ	____,
Avg. N man days between physical incapacitations	MPI	____,
Avg. duration of incapacity (days)	PID	____,
Physical capability constant, a value yielding zero Physical capability due to over exertion	ZPC	____,

Crosstraining probability
(probability of man with given specialty also being trained in each other specialty).

prime specialty

second specialty	*FORTRAN*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
____	PTT(1-10,1)	__,	__,	__,	__,	__,	__,	__,	__,	__,	__,
____	PTT(1-10,2)	__,	__,	__,	__,	__,	__,	__,	__,	__,	__,
____	PTT(1-10,3)	__,	__,	__,	__,	__,	__,	__,	__,	__,	__,
____	PTT(1-10,4)	__,	__,	__,	__,	__,	__,	__,	__,	__,	__,
____	PTT(1-10,5)	__,	__,	__,	__,	__,	__,	__,	__,	__,	__,
____	PTT(1-10,6)	__,	__,	__,	__,	__,	__,	__,	__,	__,	__,
____	PTT(1-10,7)	__,	__,	__,	__,	__,	__,	__,	__,	__,	__,
____	PTT(1-10,8)	__,	__,	__,	__,	__,	__,	__,	__,	__,	__,
____	PTT(1-10,9)	__,	__,	__,	__,	__,	__,	__,	__,	__,	__,
____	PTT(1-10,10)	__,	__,	__,	__,	__,	__,	__,	__,	__,	__,

Crew composition
number of men in each specialty at each eschelon (rank)

prime specialty

eschelon		*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
		NIP1/IP1=									
____	MEN(1-10,1)	__,	__,	__,	__,	__,	__,	__,	__,	__,	__,
____	MEN(1-10,2)	__,	__,	__,	__,	__,	__,	__,	__,	__,	__,
____	MEN(1-10,3)	__,	__,	__,	__,	__,	__,	__,	__,	__,	__,
____	MEN(1-10,4)	__,	__,	__,	__,	__,	__,	__,	__,	__,	__,

Title Cards

Description		FORTRAN	VALUE
Number of duty shifts		NDS	______,
Crew duty shift assignment			
Man	1	IDS(1-6,1)	_,_,_,_,_,_,
	2	IDS(1-6,2)	_,_,_,_,_,_,
	3	IDS(1-6,3)	_,_,_,_,_,_,
	4	IDS(1-6,4)	_,_,_,_,_,_,
	5	IDS(1-6,5)	_,_,_,_,_,_,
	6	IDS(1-6,6)	_,_,_,_,_,_,
	7	IDS(1-6,7)	_,_,_,_,_,_,
	8	IDS(1-6,8)	_,_,_,_,_,_,
	9	IDS(1-6,9)	_,_,_,_,_,_,
	10	IDS(1-6,10)	_,_,_,_,_,_,
	11	IDS(1-6,11)	_,_,_,_,_,_,
	12	IDS(1-6,12)	_,_,_,_,_,_,
	13	IDS(1-6,13)	_,_,_,_,_,_,
	14	IDS(1-6,14)	_,_,_,_,_,_,
	15	IDS(1-6,15)	_,_,_,_,_,_,
	16	IDS(1-6,16)	_,_,_,_,_,_,
	17	IDS(1-6,17)	_,_,_,_,_,_,
	18	IDS(1-6,18)	_,_,_,_,_,_,
	19	IDS(1-6,19)	_,_,_,_,_,_,
	20	IDS(1-6,20)	_,_,_,_,_,_$

Title Cards

Description	FORTRAN	VALUE
Equipment repair		*$EQREVT NFP4/FP4=*
Reliability (days between failure)	RELH	______,
Intermittent failure duration (hours)	TUI	______,
Repair maximum duration (minutes)	DTR	______,
For each event in the repair family		
Event 1 Probability of next event	PRB(1-3,1)	____,____,____,
Data change number	IEDC(1-3,1)	____,____,____,
Data change value	EDCV(1-3,1)	____,____,____,
Event 2 Probability of next event	PRB(1-3,2)	____,____,____,
Data change number	IEDC(1-3,2)	____,____,____,
Data change value	EDCV(1-3,2)	____,____,____,
Event 3 Probability of next event	PRB(1-3,3)	____,____,____,
Data change number	IEDC(1-3,3)	____,____,____,
Data change value	EDCV(1-3,3)	____,____,____,
Event 4 Probability of next event	PRB(1-3,4)	____,____,____,
Data change number	IEDC(1-3,4)	____,____,____,
Data change value	EDCV(1-3,4)	____,____,____,
Event 5 Probability of next event	PRB(1-3,5)	____,____,____,
Data change number	IEDC(1-3,5)	____,____,____,
Data change value	EDCV(1-3,5)	____,____,____,
Event 6 Probability of next event	PRB(1-3,6)	____,____,____,
Data change number	IEDC(1-3,6)	____,____,____,
Data change value	EDCV(1-3,6)	____,____,____,
Event 7 Probability of next event	PRB(1-3,7)	____,____,____,
Data change number	IEDC(1-3,7)	____,____,____,
Data change value	EDCV(1,3,7)	____,____,____,
Event 8 Probability of next event	PRB(1-3,8)	____,____,____,
Data change number	IEDC(1-3,8)	____,____,____,
Data change value	EDCV(1-3,8)	____,____,____,
Event 9 Probability of next event	PRB(1-3,9)	____,____,____,
Data change number	IEDC(1-3,9)	____,____,____,
Data change value	EDCV(1-3,9)	____,____,____,
Event 10 Probability of next event	PRB(1-3,10)	____,____,____,
Data change number	IEDC(1-3,10)	____,____,____,
Data change value	EDCV(1-3,10)	____,____,____,
Event 11 Probability of next event	PRB(1-3,11)	____,____,____,
Data change number	IEDC(1-3,11)	____,____,____,
Data change value	EDCV(1-3,11)	____,____,____,
Event 12 Probability of next event	PRB(1-3,12)	____,____,____,
Data change number	IEDC(1-3,12)	____,____,____,
Data change value	EDCV(1-3,12)	____,____,____,

Title Cards

Description	FORTRAN	VALUE
		NIP4/IP4=
Repair description		
Equipment-Number	NFQRE	________
Description (72 digits)		72H______,
Threshold (units/hour)	TSR	_______,
Threshold (units)	TSR1	_______,
Number of repair events in family	IRE	_______,
Family number	IEFN	_______,
(repeat for each repair)		
Event family members		
Event 1 Type number	IETYP	_______,
Precedent events	IPE	_______,
Next events	NX(1-3,1)	___,___,___,
Repair/Touch up (1,2,3)	RTU	_______,
Event family indicator (0,1,2)	IFOI	_______,
Event 2 Type number	IETYP	_______,
Precedent events	IPE	_______,
Next events	NX(1-3,2)	___,___,___,
Repair/Touch up	RTU	_______,
Event family indicator	IFOI	_______,
Event 3 Type number	IETYP	_______,
Precedent events	IPE	_______,
Next events	NX(1-3,3)	___,___,___,
Repair/Touch up	RTU	_______,
Event family indicator	IFOI	_______,
Event 4 Type number	IETYP	_______,
Precedent events	IPE	_______,
Next events	NX(1-3,4)	___,___,___,
Repair/Touch up	RTU	_______,
Event family indicator	IFOI	_______,
Event 5 Type number	IETYP	_______,
Precedent events	IPE	_______,
Next events	NX(1-3,5)	___,___,___,
Repair/Touch up	RTU	_______,
Event family indicator	IFOI	_______,
Event 6 Type number	IETYP	_______,
Precedent events	IPE	_______,
Next events	NX(1-3,6)	___,___,___,
Repair/Touch up	RTU	_______,
Event family indicator	IFOI	_______,
Event 7 Type number	IETYP	_______,
Precedent events	IPE	_______,
Next events	NX(1-3,7)	___,___,___,
Repair/Touch up	RTU	_______,
Event family indicator	IFOI	_______,

Title Cards

Description	FORTRAN	VALUE
Event 8 Type number	IETYP	________,
Precedent events	IPE	________,
Next events	NX(1-3,8)	___,___,___,
Repair/Touch up	RTU	________,
Event family indicator	IFOI	________,
Event 9 Type number	IETYP	________,
Precedent events	IPE	
next events	NX(1-3,9)	___,___,___,
Repair/Touch up	RTU	________,
Event family indicator	IFOI	________,
Event 10 Type number	IETYP	________
Precedent events	IPE	________,
Next events	NX(1-3,10)	___,___,___,
Repair/Touch up	RTU	________,
Event family indicator	IFOI	________,
Event 11 Type number	IETYP	________,
Precedent events	IPE	________,
Next events	NX(1-3,11)	___,___,___,
Repair/Touch up	RTU	________,
Event family indicator	IFOI	________,
Event 12 Type number	IETYP	________,
Precedent events	IPE	________,
Next events	NX(1-3,12)	___,___,___,
Repair/Touch up	RTU	________,
Event family indicator	IFOI	________ $

(repeat for each repair--up to twelve events)

Title Cards

Description	FORTRAN	VALUE
		$EMREVT
		NIP5/IP5=
Emergencies		
Emergency: Description		72H______,
Essentiality	IESSE	______,
Men required (by type)	NREQE(1-5,1)	_,_,_,_,_,
	NREQE(6-10,1)	_,_,_,_,_,
Mental load	LODME	______,
Rate of consumable expenditure (units/hours)	IRCE(1-5,1)	_,_,_,_,_,
	IRCE(6-10,1)	_,_,_,_,_,
Threshold (units/hours)	TSE	______,
	IRCE1(1-5,1)	_,_,_,_,_,
	IRCE1(6-10,1)	_,_,_,_,_,
Threshold (units)	TSE1	______,
Hazard class	IHE	______,
Energy consumption (calories/hr)	IECE(1-5,1)	_,_,_,_,_,
	IECE(6-10,1)	_,_,_,_,_,
Number days between emergencies	NDBE	______,
(repeat for each emergency)		
		NFP5/FP5=
Average recovery time (hours)	ART	______,
Average standard deviation of recovery time (hours)	ASDE	______,
Duration target (hours)	DTE	______ $
(repeat for each emergency)		
Event type data		*$TYPE*
		NIP6/IP6=
Description		72H______,
Essentiality	IESS	______,
Number of men required (by type)	NREQ(1-5,1)	_,_,_,_,_,
	NREQ(6-10,1)	_,_,_,_,_,
Mental load	LODM	______,
Kind of event end time	KE	______,
Kind of event	INT	______,
Rate of expenditure of consumables (units/hours)	IRC(1-5,1)	_,_,_,_,_,
	IRC(6-10,1)	_,_,_,_,_,
Rate of expenditure of consumables (units)	IRC1(1-5,1)	_,_,_,_,_,
	IRC1(6-10,1)	_,_,_,_,_,
Hazard class	IH	______,
Energy consumption (cal./hr.)	IEC(1-5,1)	_,_,_,_,_,
	IEC(6-10,1)	_,_,_,_,_,
Number of equipments required	NIQR	_,_,_,_,_,_,
Equipments required	IQR(1-6)	______,
Class	ICLASS	______

(repeat foe each event type)

Title Cards

Description	FORTRAN	Value
		NFP6/FP6=
Average duration (hours)	ADUR	________,
Average standard deviation	ASD	________,
Average duration (hours)	ADUR	________,
Average standard deviation	ASD	________,
Average duration (hours)	ADUR	________,
Average standard deviation	ASD	________,
Average duration (hours)	ADUR	________,
Average standard deviation	ASD	________,
Average duration (hours)	ADUR	________,
Average standard deviation	ASD	________,
Average duration (hours)	ADUR	________,
Average standard deviation	ASD	________,
Average duration (hours)	ADUR	________,
Average standard deviation	ASD	________,
Average duration (hours)	ADUR	________,
Average standard deviation	ASD	________,
Average duration (hours)	ADUR	________,
Average standard deviation	ASD	________,
Average duration (hours)	ADUR	________,
Average standard deviation	ASD	________,
Average duration (hours)	ADUR	________,
Average standard deviation	ASD	________,
Average duration (hours)	ADUR	________,
Average standard deviation	ASD	________,
Average duration (hours)	ADUR	________,
Average standard deviation	ASD	________,
Average duration (hours)	ADUR	________,
Average standard deviation	ASD	________,
Average duration (hours)	ADUR	________,
Average standard deviation	ASD	________,
Average duration (hours)	ADUR	________,
Average standard deviation	ASD	________,
Average duration (hours)	ADUR	________,
Average standard deviation	ASD	________,
Average duration (hours)	ADUR	________,
Average standard deviation	ASD	________,
Average duration (hours)	ADUR	________,
Average standard deviation	ASD	________,
Average duration (hours)	ADUR	________,
Average standard deviation	ASD	________,

Title Cards Description	FORTRAN	VALUE
		NFP6/FP6=
Average duration (hours)	ADUR	________,
Average standard deviation	ASD	________ $
(repeat for each event type)		

Scheduled events title card	FORTRAN	FORMAT	VALUE
(Input card not free format)			
Day number for this iteration	ND	I3	_ _ _
Number of scheduled events this iteration	NOSE	I3	_ _ _
Title		11A6	(66 spaces)

Scheduled events	FORTRAN	VALUE
		$SCHEVT
		NIP3/IP3=
Type	IETYP	________,
Precedent events	IPE	________,
Threshold (units/hour)	TS	________,
Threshold (units)	TS1	________,
Repair/Touchup	RTU	________,
Event family indicator	IFOI	________,
Number in family	NIF	________,
Family number	IEFN	________,
Next events	NX(1-3,1)	__,__,__,
(repeat for each scheduled event)		
		NFP3/FP3=
Time limit	TL	________,
Start time (hours)	ST	________,
Probability of alternatives	PRB(1-3,1)	________,
Data change number	IEDC(1-3,1)	________,
Data change value	EDCV(1-3,1)	________ $

(repeat for each scheduled event)

APPENDIX C

Logic Flow Charts

I

a

COUNT NUMBER OF MEN IN CREW
BY CREW ECHELON AS FOLLOWS:

$$IAA\ (i) = \sum_{j=1}^{10} MEN\ (j,\ i) \qquad i = 1,2,3,4 \quad j = 1,2,\cdots,NTMAX$$

ICE = i = 1 FOR OFFICERS
= 2 FOR SENIOR P.O.'s
= 3 FOR JUNIOR P.O.'s
= 4 FOR UNRATED MEN

$$\text{NUMBER OF MEN IN CREW} = IC = \sum_{i=1}^{4} IAA\ (i)$$

ASSIGN TO EACH CREW MEMBER A MEMBER ID M (M = 1, 2 . . . , IC) AND A CREW ECHELON NUMBER ICE (M) SUCH THAT IF $ICE(M_1) < ICE(M_2)$ THEN $M_1 < M_2$

ASSIGN PRIMARY SPECIALTY IPS(M) FOR EACH CREW MEMBER M WHERE THE NUMBER OF MEN HAVING A GIVEN IPS(M) = NT IS DETERMINED BY MEN(ICE, NT)

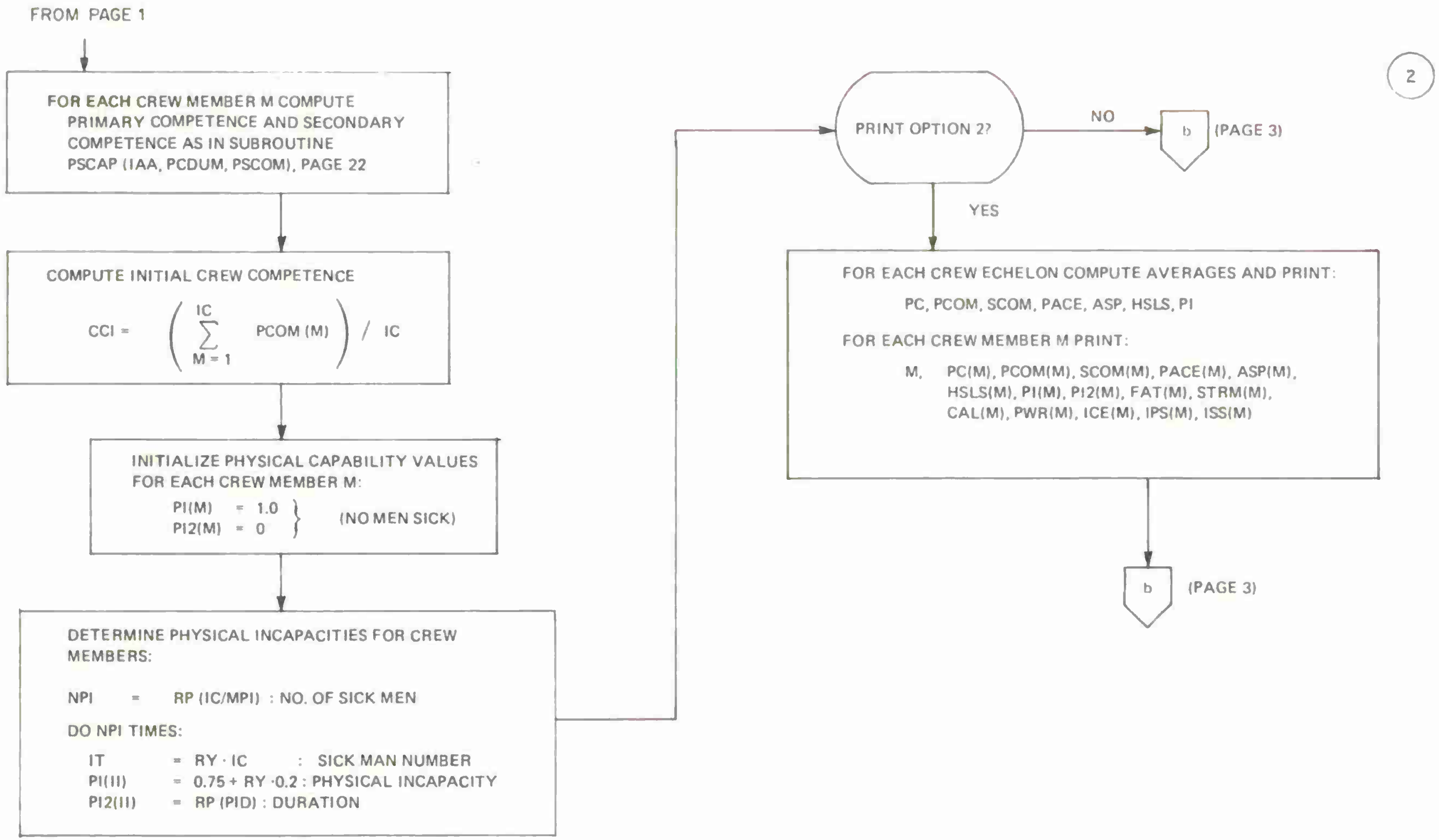
DETERMINE SECONDARY SPECIALTY ISS(M) FOR EACH CREW MEMBER M AS FOLLOWS:

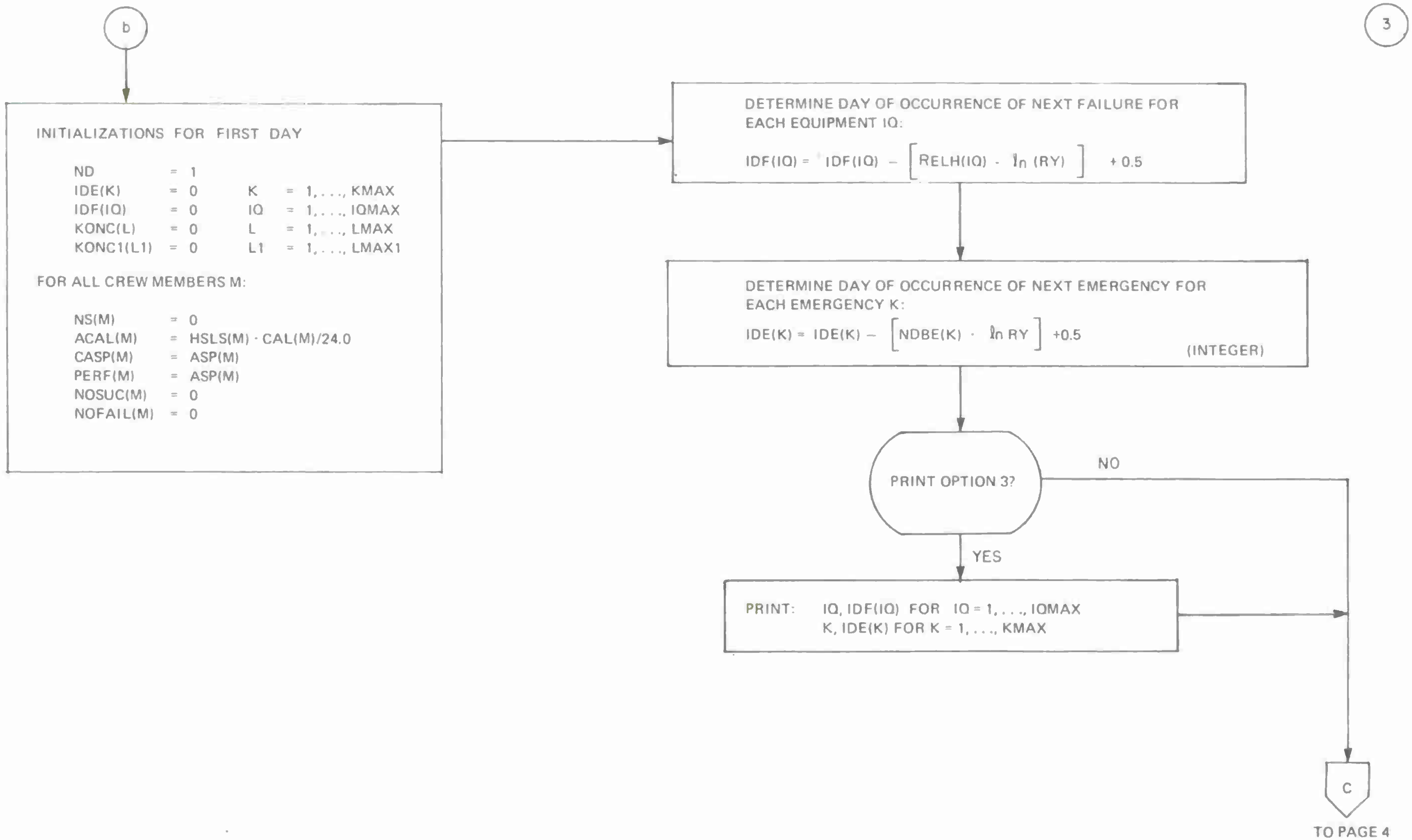
ISS(M) = MINIMUM PERSONNEL TYPE IT SUCH THAT
$PTT\ (IT,\ IPS(M)) \geq RY \cdot PTT\ (10,\ IPS(M))$

FOR EACH CREW MEMBER M INITIALIZE ATTRIBUTES:

PC(M)	=	$(WT + RD \cdot SIGWT)/WT$
CAL(M)	=	$PC(M) \cdot CALRY$
PWR(M)	=	$PC(M) \cdot PWRRT$
PACE(M)	=	$ACP + 0.11 \cdot RD$
ASP(M)	=	$(AASP + RD \cdot AASP/10) \leq 1$
HSLS(M)	=	$SLEEP + RD \cdot SLEEP/4$
FAT(M)	=	f (HSLS) as in subroutine FBUILD (Page 22)
STRM(M)	=	$APST + RD \cdot APST\ 16$

TO PAGE 2


FROM PAGE 1
FOR EACH CREW MEMBER M COMPUTE PRIMARY COMPETENCE AND SECONDARY COMPETENCE AS IN SUBROUTINE PSCAP (IAA, PCDUM, PSCOM), PAGE 22
COMPUTE INITIAL CREW COMPETENCE
$CCI = \left(\sum_{M=1}^{IC} PCOM(M) \right) / IC$
INITIALIZE PHYSICAL CAPABILITY VALUES FOR EACH CREW MEMBER M:
PI(M) = 1.0
PI2(M) = 0
(NO MEN SICK)
DETERMINE PHYSICAL INCAPACITIES FOR CREW MEMBERS:
NPI = RP (IC/MPI) : NO. OF SICK MEN
DO NPI TIMES:
IT = RY · IC : SICK MAN NUMBER
PI(II) = 0.75 + RY ·0.2 : PHYSICAL INCAPACITY
PI2(II) = RP (PID) : DURATION
PRINT OPTION 2?
NO
b
(PAGE 3)
YES
FOR EACH CREW ECHELON COMPUTE AVERAGES AND PRINT:
PC, PCOM, SCOM, PACE, ASP, HSLS, PI
FOR EACH CREW MEMBER M PRINT:
M, PC(M), PCOM(M), SCOM(M), PACE(M), ASP(M), HSLS(M), PI(M), PI2(M), FAT(M), STRM(M), CAL(M), PWR(M), ICE(M), IPS(M), ISS(M)
b
(PAGE 3)
2



b
3
INITIALIZATIONS FOR FIRST DAY
ND = 1
IDE(K) = 0 K = 1, . . ., KMAX
IDF(IQ) = 0 IQ = 1, . . ., IQMAX
KONC(L) = 0 L = 1, . . ., LMAX
KONC1(L1) = 0 L1 = 1, . . ., LMAX1
FOR ALL CREW MEMBERS M:
NS(M) = 0
ACAL(M) = HSLS(M) · CAL(M)/24.0
CASP(M) = ASP(M)
PERF(M) = ASP(M)
NOSUC(M) = 0
NOFAIL(M) = 0
DETERMINE DAY OF OCCURRENCE OF NEXT FAILURE FOR EACH EQUIPMENT IQ:
IDF(IQ) = IDF(IQ) – [RELH(IQ) · ln (RY)] + 0.5
DETERMINE DAY OF OCCURRENCE OF NEXT EMERGENCY FOR EACH EMERGENCY K:
IDE(K) = IDE(K) – [NDBE(K) · ln RY] +0.5
(INTEGER)
PRINT OPTION 3?
NO
YES
PRINT: IQ, IDF(IQ) FOR IQ = 1, . . ., IQMAX
K, IDE(K) FOR K = 1, . . ., KMAX
C
TO PAGE 4

C

INITIALIZATIONS FOR EACH DAY:

NIGNR	= 0
NSUC1	= 0
NSUC2	= 0
NFALE	= 0
NREPT	= 0
NPRFM	= 0
HRSE	= 0.0
HRSR	= 0.0
HRSS	=0.0
MAXST	= 0
MAXSTE	= 0
IGIND	= 0
CML	= 0.0
CMLMX	= 1.E10
ICML	= 0
TEH	= 0
USHT	= 0
APA	= 0
ISIE	= 0
SEF	= 0

FOR EACH CREW MEMBER M:

TW(M)	= 0.0
TWP(M)	= 0.0
TWS(M)	= 0.0
MPCC(M)	= 0.0
IDC(M)	= 0.0
DS(M)	= 0.0
NU(M)	= 0.0
Z(M)	= 0.0

FOR EACH EQUIPMENT IQ:

CUT(IQ)	= 0.0
CDT(IQ)	= 0.0
CART(IQ)	= 0.0

ZC(IE) = 0 for all IE

CALCULATE SEASTATE AND PERCENT CREW SEASICK:

ICSS = MINIMUM VALUE OF IS FOR WHICH SESTA(IS) $\geq$ RY

PSESIC = 0.0555 · ICSS

DETERMINE SEASICK STATUS OF EACH M AND ADJUST COMPETENCE FOR EACH M:

IF RY < PSESIC:

TPCOM(M) = PCOM(M) · $\left[1 - 0.0555 \cdot \text{ICSS}\right]$

TSCOM(M) = SCOM(M) · $\left[1 - 0.0555 \cdot \text{ICSS}\right]$

4

CALL DINPUT SUBROUTINE TO READ SCHEDULED EVENT SEQUENCE DATA FOR DAY AND TO PRINT DATA IF PRINT OPTION IS IN EFFECT

NOSE = NUMBER OF SCHEDULED EVENTS FOR DAY

IEVENT(i) = i WHERE i = 1, . . ., NOSE

IDENTIFY NUMBER AND PLACEMENT OF REPAIR EVENTS FOR EQUIPMENT HARD FAILURES

INITIALIZE NR = 0

FOR EACH IQ SUCH THAT IDF(IQ) = ND:

1. NR = NR + 1 $\leq$ 30
2. IDF(IQ) = IDF(IQ) – $\left[\text{FAIL(IQ)} \cdot \ln \text{(RY)}\right]$ + 0.5
3. IEVENT (NOSE + NR) = 200 + 12 (IQ-1) + 1

IDENTIFY & PLACE EMERGENCY EVENTS:

INITIALIZE: NE = 0

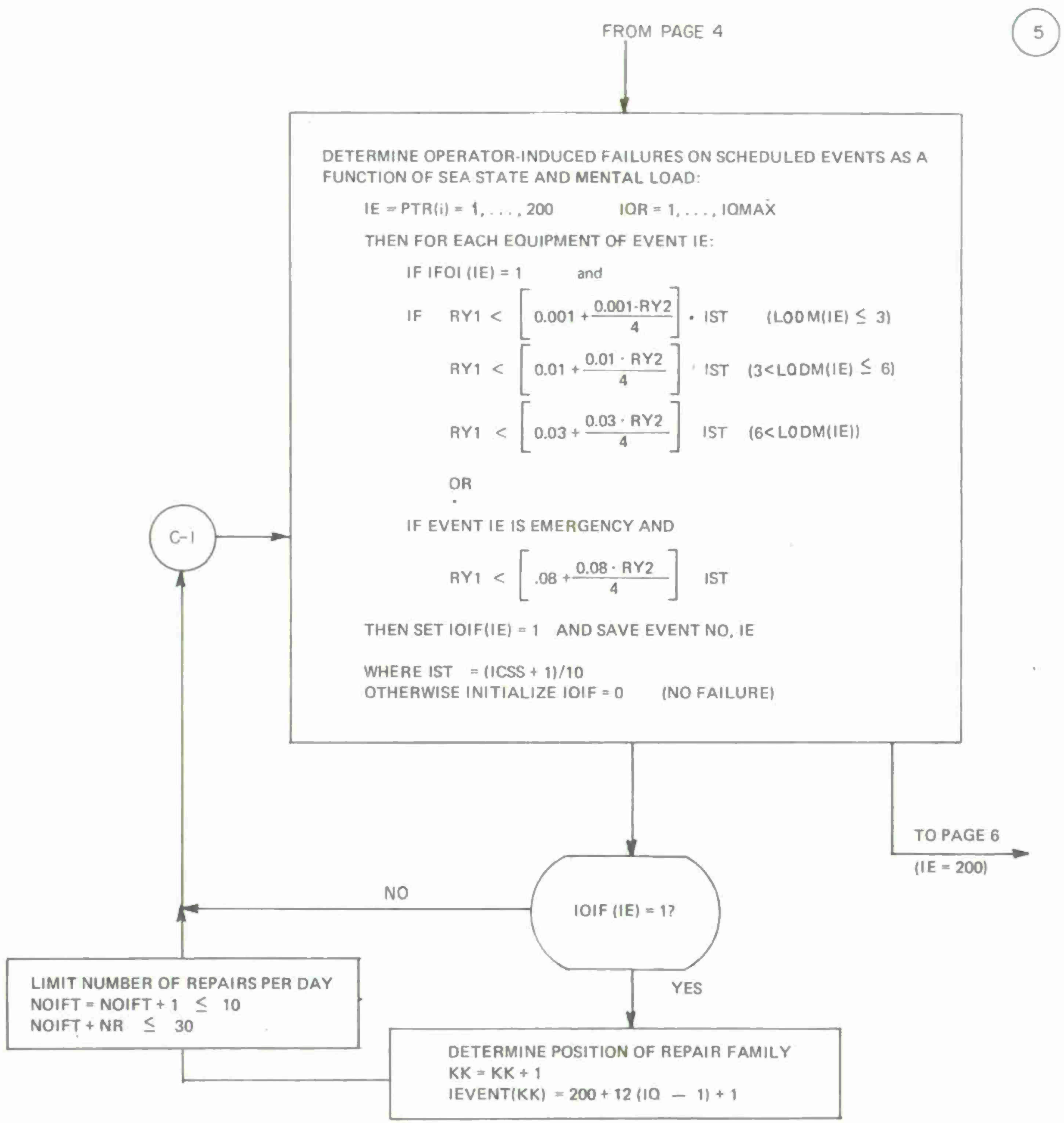
FOR EACH K SUCH THAT IDE(K) = ND:

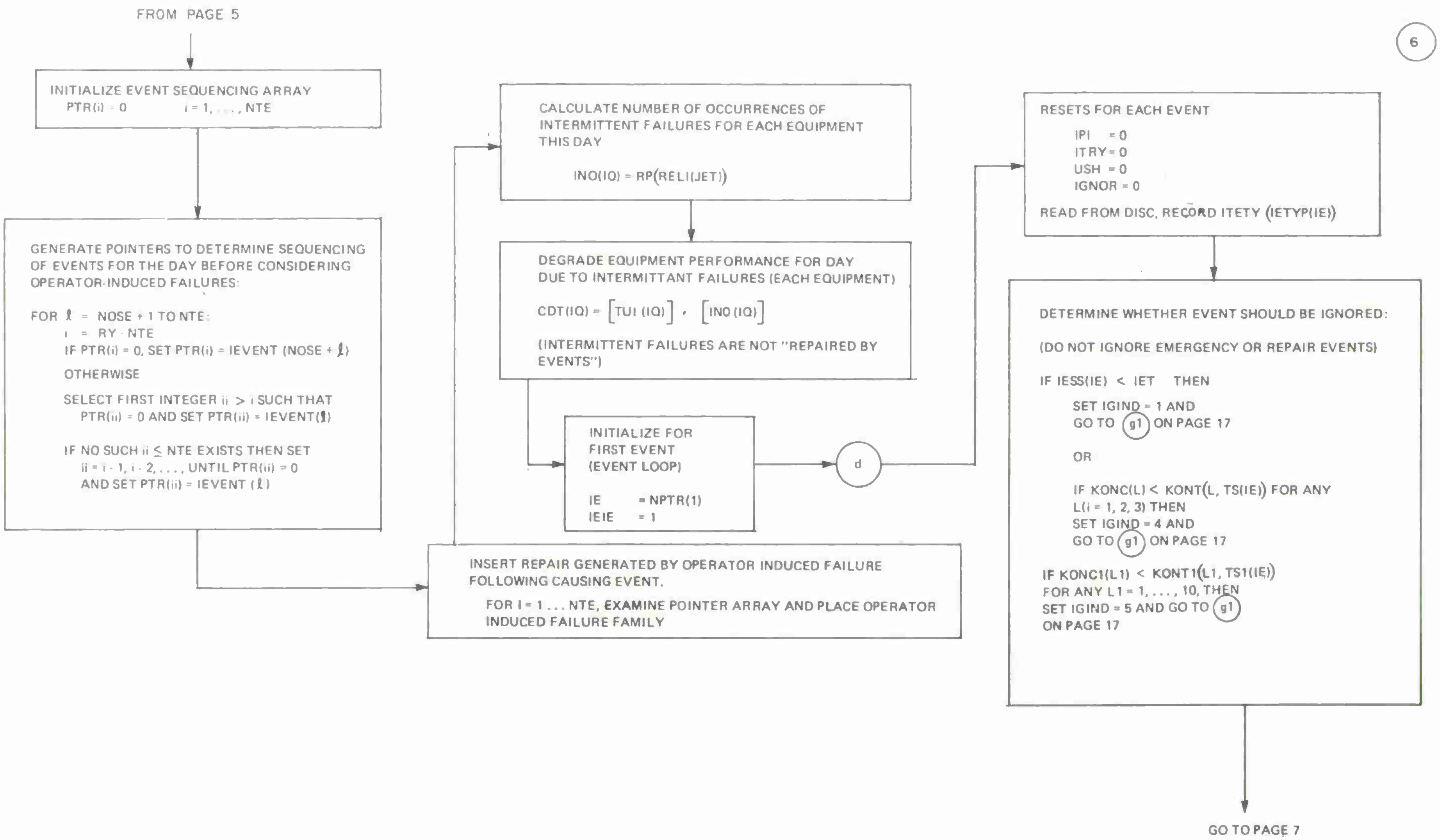
1. NE = NE + 1
2. IEVENT (NOSE + NR + NE) = 560 + K
3. IDE(K) = IDE(K) + $\left[\text{NDBE(K)} \cdot \ln \text{(RY)}\right]$ + 0.5

SUM TOTAL NUMBER OF EVENTS

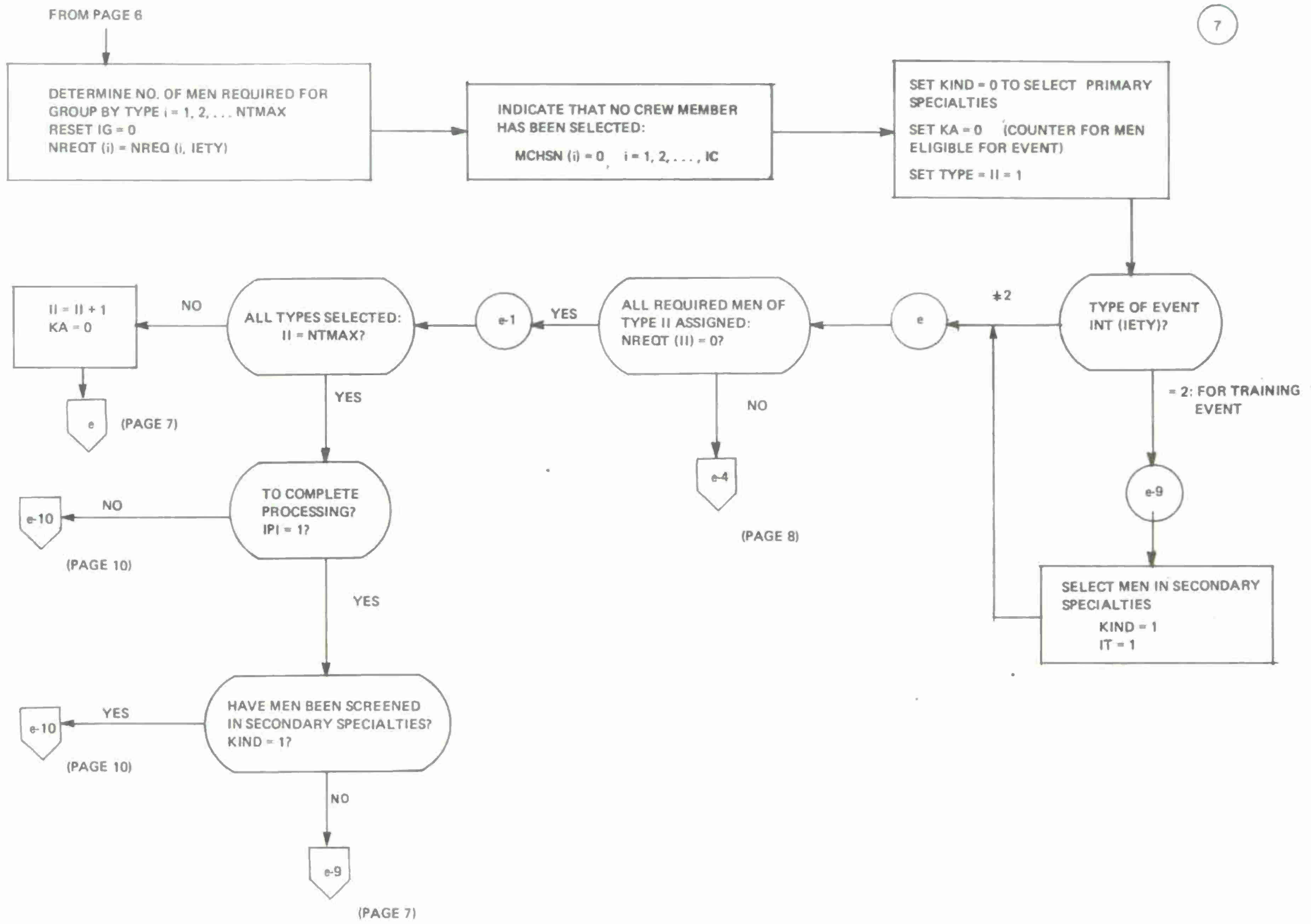
NTE = NOSE(ND) + NE + NR

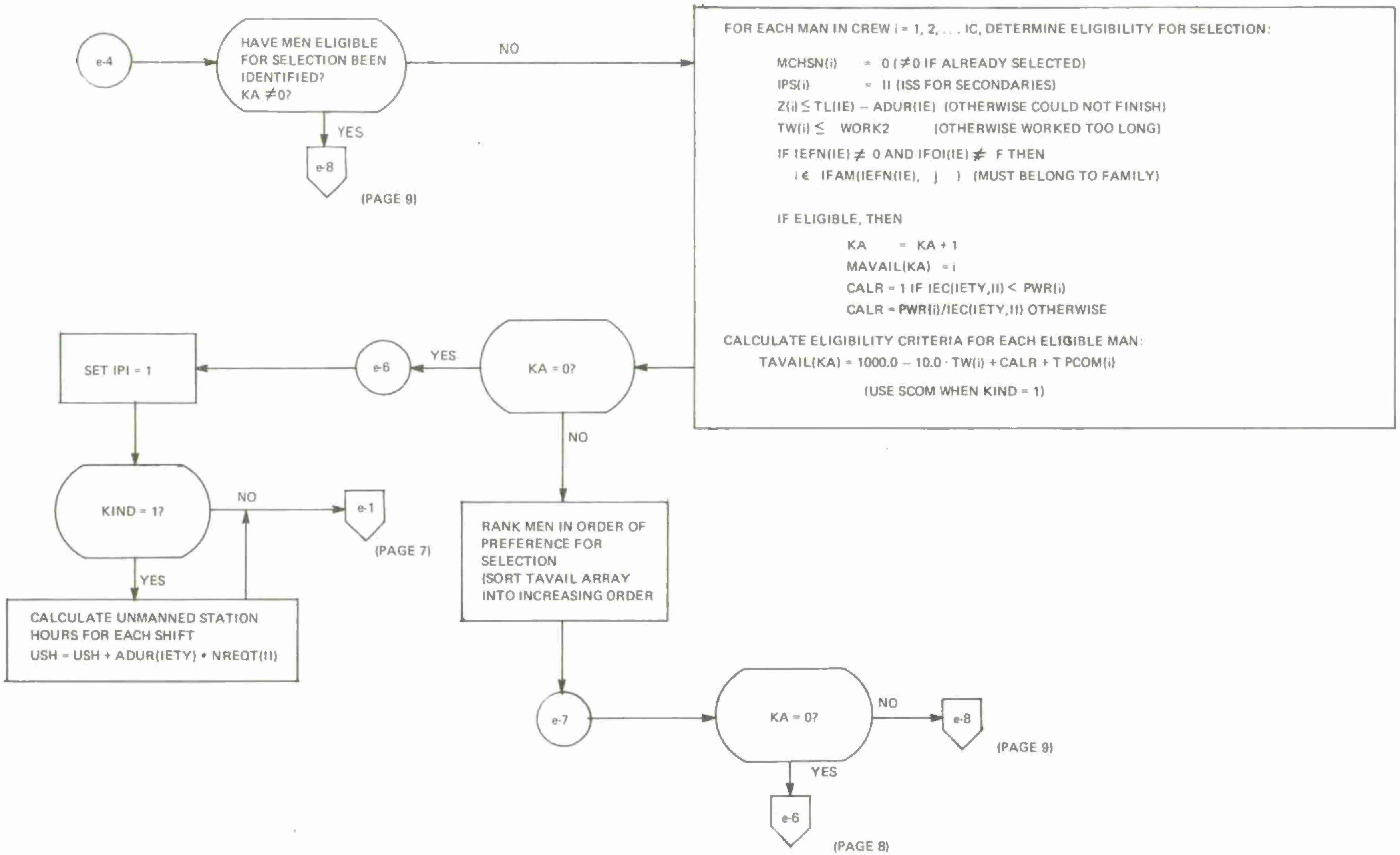
to page 5

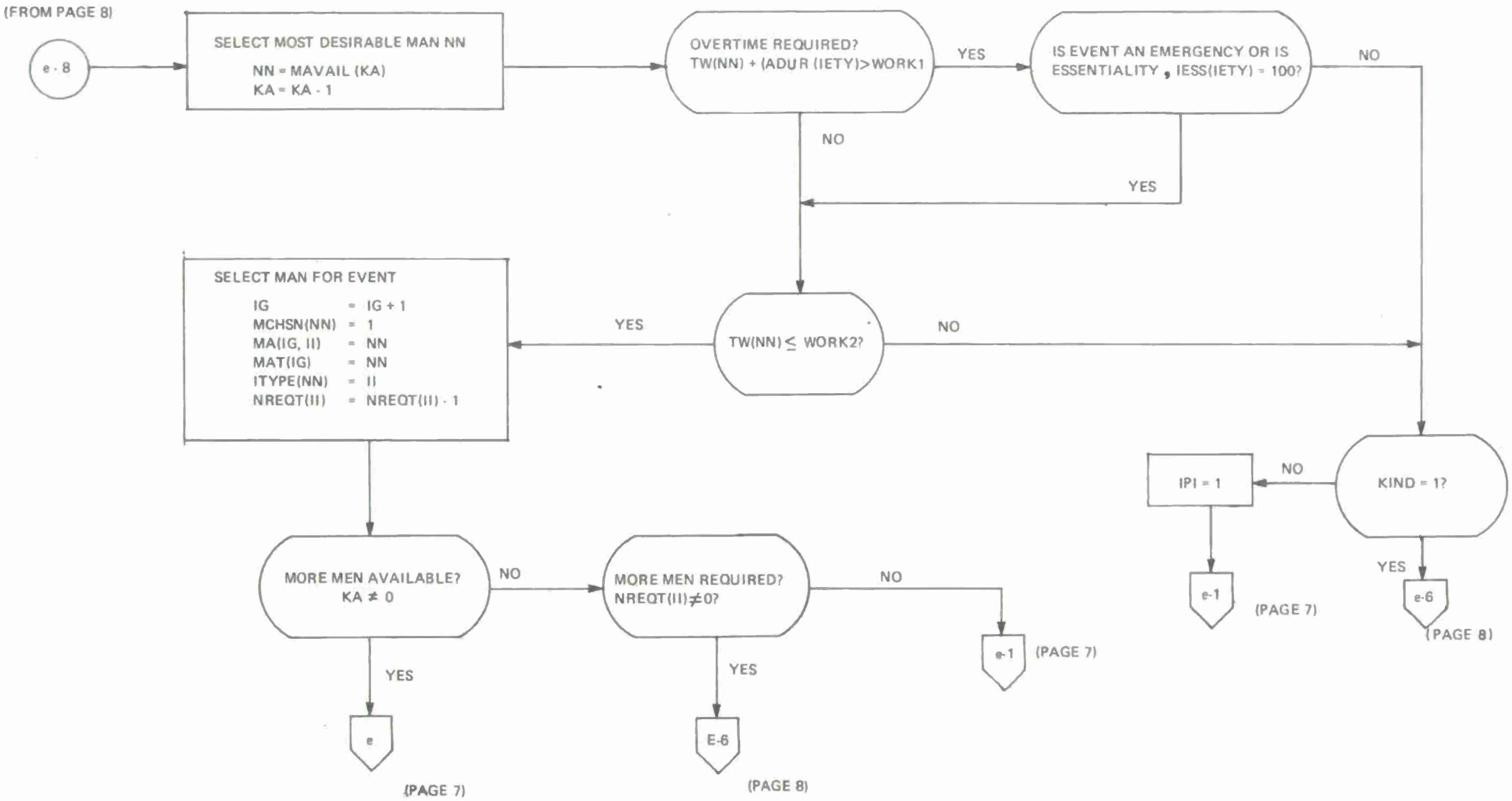

FROM PAGE 4
5
DETERMINE OPERATOR-INDUCED FAILURES ON SCHEDULED EVENTS AS A FUNCTION OF SEA STATE AND MENTAL LOAD:
IE = PTR(i) = 1, . . . , 200   IQR = 1, . . . , IQMAX
THEN FOR EACH EQUIPMENT OF EVENT IE:
IF IFOI (IE) = 1 and
IF RY1 < [0.001 + 0.001·RY2 / 4] · IST (LODM(IE) ≤ 3)
RY1 < [0.01 + 0.01 · RY2 / 4] · IST (3<LODM(IE) ≤ 6)
RY1 < [0.03 + 0.03 · RY2 / 4] IST (6<LODM(IE))
OR
IF EVENT IE IS EMERGENCY AND
RY1 < [.08 + 0.08 · RY2 / 4] IST
THEN SET IOIF(IE) = 1 AND SAVE EVENT NO, IE
WHERE IST = (ICSS + 1)/10
OTHERWISE INITIALIZE IOIF = 0 (NO FAILURE)
C-I
TO PAGE 6
(IE = 200)
NO
IOIF (IE) = 1?
YES
LIMIT NUMBER OF REPAIRS PER DAY
NOIFT = NOIFT + 1 ≤ 10
NOIFT + NR ≤ 30
DETERMINE POSITION OF REPAIR FAMILY
KK = KK + 1
IEVENT(KK) = 200 + 12 (IQ — 1) + 1

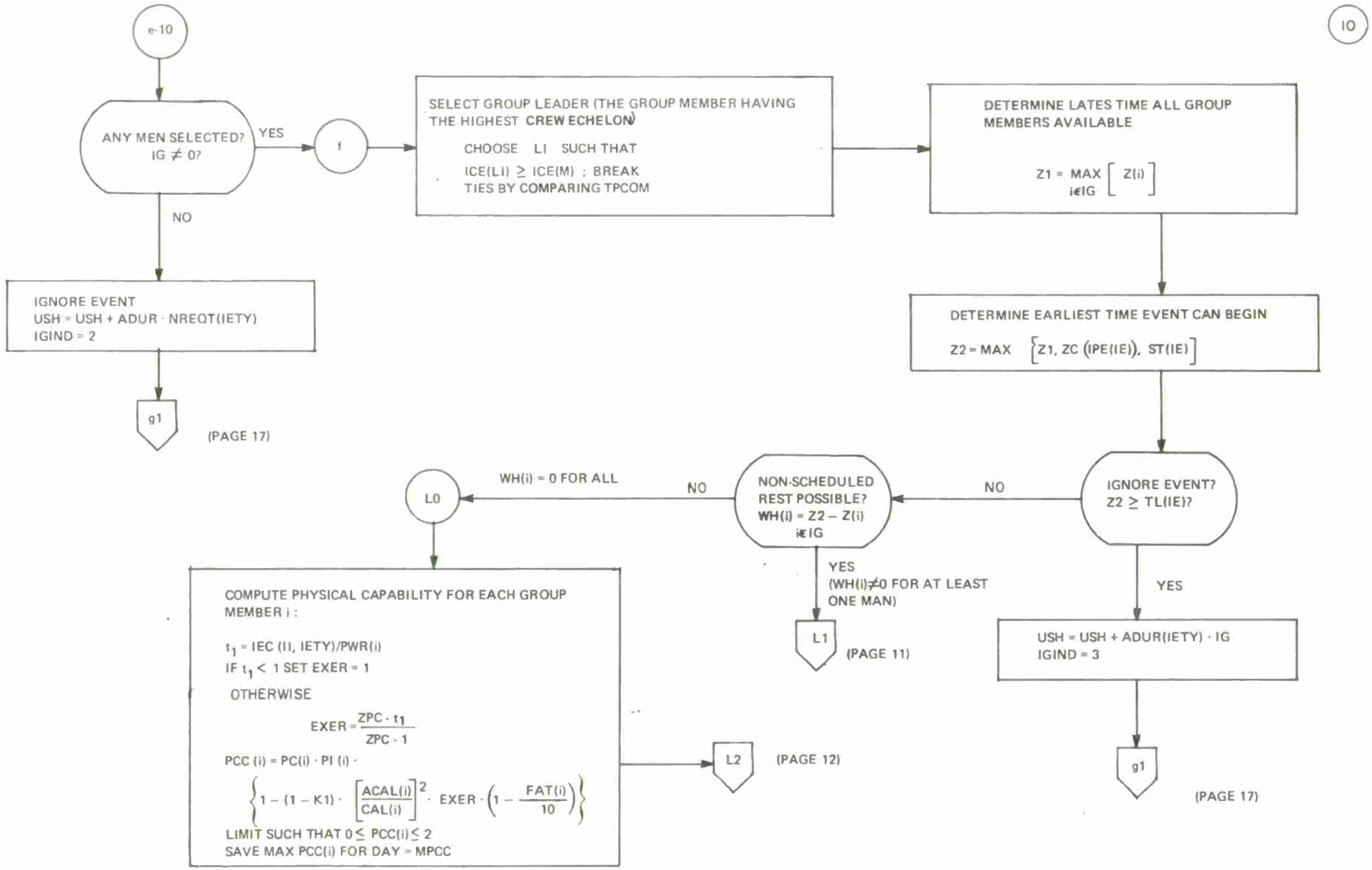


6
FROM PAGE 5
INITIALIZE EVENT SEQUENCING ARRAY
PTR(i) = 0 i = 1, . . . , NTE
GENERATE POINTERS TO DETERMINE SEQUENCING OF EVENTS FOR THE DAY BEFORE CONSIDERING OPERATOR-INDUCED FAILURES:
FOR ℓ = NOSE + 1 TO NTE:
i = RY · NTE
IF PTR(i) = 0, SET PTR(i) = IEVENT (NOSE + ℓ)
OTHERWISE
SELECT FIRST INTEGER ii > i SUCH THAT PTR(ii) = 0 AND SET PTR(ii) = IEVENT(ℓ)
IF NO SUCH ii ≤ NTE EXISTS THEN SET ii = i - 1, i - 2, . . . , UNTIL PTR(ii) = 0 AND SET PTR(ii) = IEVENT (ℓ)
CALCULATE NUMBER OF OCCURRENCES OF INTERMITTENT FAILURES FOR EACH EQUIPMENT THIS DAY
INO(IQ) = RP(RELI(JET))
DEGRADE EQUIPMENT PERFORMANCE FOR DAY DUE TO INTERMITTANT FAILURES (EACH EQUIPMENT)
CDT(IQ) = [TUI (IQ)] · [INO (IQ)]
(INTERMITTENT FAILURES ARE NOT "REPAIRED BY EVENTS")
INITIALIZE FOR FIRST EVENT (EVENT LOOP)
IE = NPTR(1)
IEIE = 1
d
INSERT REPAIR GENERATED BY OPERATOR INDUCED FAILURE FOLLOWING CAUSING EVENT.
FOR I = 1 . . . NTE, EXAMINE POINTER ARRAY AND PLACE OPERATOR INDUCED FAILURE FAMILY
RESETS FOR EACH EVENT
IPI = 0
ITRY = 0
USH = 0
IGNOR = 0
READ FROM DISC, RECORD ITETY (IETYP(IE))
DETERMINE WHETHER EVENT SHOULD BE IGNORED:
(DO NOT IGNORE EMERGENCY OR REPAIR EVENTS)
IF IESS(IE) < IET THEN
SET IGIND = 1 AND GO TO g1 ON PAGE 17
OR
IF KONC(L) < KONT(L, TS(IE)) FOR ANY L(i = 1, 2, 3) THEN SET IGIND = 4 AND GO TO g1 ON PAGE 17
IF KONC1(L1) < KONT1(L1, TS1(IE)) FOR ANY L1 = 1, . . . , 10, THEN SET IGIND = 5 AND GO TO g1 ON PAGE 17
GO TO PAGE 7


FROM PAGE 6
7
DETERMINE NO. OF MEN REQUIRED FOR GROUP BY TYPE i = 1, 2, . . . NTMAX
RESET IG = 0
NREQT (i) = NREQ (i, IETY)
INDICATE THAT NO CREW MEMBER HAS BEEN SELECTED:
MCHSN (i) = 0, i = 1, 2, . . . , IC
SET KIND = 0 TO SELECT PRIMARY SPECIALTIES
SET KA = 0 (COUNTER FOR MEN ELIGIBLE FOR EVENT)
SET TYPE = II = 1
TYPE OF EVENT INT (IETY)?
≠2
= 2: FOR TRAINING EVENT
e
ALL REQUIRED MEN OF TYPE II ASSIGNED: NREQT (II) = 0?
YES
NO
e-1
e-4
(PAGE 8)
ALL TYPES SELECTED: II = NTMAX?
NO
YES
II = II + 1
KA = 0
e
(PAGE 7)
TO COMPLETE PROCESSING? IPI = 1?
NO
YES
e-10
(PAGE 10)
HAVE MEN BEEN SCREENED IN SECONDARY SPECIALTIES? KIND = 1?
YES
NO
e-10
(PAGE 10)
e-9
(PAGE 7)
e-9
SELECT MEN IN SECONDARY SPECIALTIES
KIND = 1
IT = 1


e-4
HAVE MEN ELIGIBLE FOR SELECTION BEEN IDENTIFIED? KA ≠ 0?
NO
YES
e-8
(PAGE 9)
FOR EACH MAN IN CREW i = 1, 2, . . . IC, DETERMINE ELIGIBILITY FOR SELECTION:
MCHSN(i) = 0 (≠ 0 IF ALREADY SELECTED)
IPS(i) = II (ISS FOR SECONDARIES)
Z(i) ≤ TL(IE) – ADUR(IE) (OTHERWISE COULD NOT FINISH)
TW(i) ≤ WORK2 (OTHERWISE WORKED TOO LONG)
IF IEFN(IE) ≠ 0 AND IFOI(IE) ≠ F THEN
i ∈ IFAM(IEFN(IE), j) (MUST BELONG TO FAMILY)
IF ELIGIBLE, THEN
KA = KA + 1
MAVAIL(KA) = i
CALR = 1 IF IEC(IETY,II) < PWR(i)
CALR = PWR(i)/IEC(IETY,II) OTHERWISE
CALCULATE ELIGIBILITY CRITERIA FOR EACH ELIGIBLE MAN:
TAVAIL(KA) = 1000.0 – 10.0 · TW(i) + CALR + T PCOM(i)
(USE SCOM WHEN KIND = 1)
SET IPI = 1
e-6
YES
KA = 0?
NO
KIND = 1?
NO
e-1
(PAGE 7)
YES
CALCULATE UNMANNED STATION HOURS FOR EACH SHIFT
USH = USH + ADUR(IETY) • NREQT(II)
RANK MEN IN ORDER OF PREFERENCE FOR SELECTION (SORT TAVAIL ARRAY INTO INCREASING ORDER
e-7
KA = 0?
NO
e-8
(PAGE 9)
YES
e-6
(PAGE 8)


(FROM PAGE 8)
e - 8
SELECT MOST DESIRABLE MAN NN
NN = MAVAIL (KA)
KA = KA - 1
OVERTIME REQUIRED?
TW(NN) + (ADUR (IETY)>WORK1
YES
IS EVENT AN EMERGENCY OR IS ESSENTIALITY, IESS(IETY) = 100?
NO
NO
YES
SELECT MAN FOR EVENT
IG = IG + 1
MCHSN(NN) = 1
MA(IG, II) = NN
MAT(IG) = NN
ITYPE(NN) = II
NREQT(II) = NREQT(II) - 1
YES
TW(NN) ≤ WORK2?
NO
NO
IPI = 1
KIND = 1?
YES
e-1
(PAGE 7)
e-6
(PAGE 8)
MORE MEN AVAILABLE?
KA ≠ 0
NO
MORE MEN REQUIRED?
NREQT(II)≠0?
NO
e-1
(PAGE 7)
YES
e
(PAGE 7)
YES
E-6
(PAGE 8)


e-10
10
ANY MEN SELECTED? IG ≠ 0?
YES
NO
f
SELECT GROUP LEADER (THE GROUP MEMBER HAVING THE HIGHEST CREW ECHELON)
CHOOSE LI SUCH THAT
ICE(LI) ≥ ICE(M) ; BREAK TIES BY COMPARING TPCOM
DETERMINE LATES TIME ALL GROUP MEMBERS AVAILABLE
Z1 = MAX i∈IG [Z(i)]
IGNORE EVENT
USH = USH + ADUR · NREQT(IETY)
IGIND = 2
g1
(PAGE 17)
DETERMINE EARLIEST TIME EVENT CAN BEGIN
Z2 = MAX [Z1, ZC (IPE(IE)), ST(IE)]
IGNORE EVENT? Z2 ≥ TL(IE)?
NO
YES
NON-SCHEDULED REST POSSIBLE? WH(i) = Z2 – Z(i) i∈IG
NO
WH(i) = 0 FOR ALL
L0
YES (WH(i)≠0 FOR AT LEAST ONE MAN)
L1
(PAGE 11)
USH = USH + ADUR(IETY) · IG
IGIND = 3
g1
(PAGE 17)
COMPUTE PHYSICAL CAPABILITY FOR EACH GROUP MEMBER i :
t1 = IEC (II, IETY)/PWR(i)
IF t1 < 1 SET EXER = 1
OTHERWISE
EXER = (ZPC · t1)/(ZPC · 1)
PCC (i) = PC(i) · PI (i) ·
{1 – (1 – K1) · [ACAL(i)/CAL(i)]^2 · EXER · (1 – FAT(i)/10)}
LIMIT SUCH THAT 0 ≤ PCC(i) ≤ 2
SAVE MAX PCC(i) FOR DAY = MPCC
L2
(PAGE 12)

(11)

(L1) →

FOR EACH MAN i IN THE GROUP CALCULATE SLEEP AND FATIGUE RELIEF:

WH(i) $\geq$ CN + 0.5? (TIME TO SLEEP?)

IF NO, EXIT TO (X1)

DS(i) $\geq$ MAXSL? (SLEEP QUOTA FILLED?)

IF YES, EXIT TO (X1)

FAT(i) $\leq$ TFAT (FATIGUE UNDER THRESHOLD?)

IF YES, EXIT TO (X1)

SUM SLEEP FOR DAY:

$$DS(i) = MIN\left[MAXSL,\ DS(i) + WH(i) - 0.5\right]$$

COMPUTE FATIGUE DUE TO SLEEP:

$$TEM1 = MIN\left[MAXSL - DS(i),\ WH(i) - 0.5\right]$$

IF TEM 1 > 9, FAT(i) = 0.0

IF 1 $\leq$ TEM1 $\leq$ 9, FAT(i) =

$$FAT(i) \cdot \left[\frac{69}{70} - \frac{19}{140}\ TEM1 + 0.2\ RY\right]$$

IF 0 $\leq$ TEM1 < 1, FAT(i) =

$$FAT(i) \cdot \left[0.9 - 0.05 \cdot TEM1 + 0.2\ RY\right]$$

LIMIT SUCH THAT 0 $\leq$ FAT(i) $\leq$ 1

RESET CALORIES EXPENDED SINCE LAST SLEEP: ACAL(i) = 0

COMPUTE HOURS SINCE LAST SLEEP EQUIVALENT:

IF FAT(i) < .15, $HSLS(i) = \frac{160}{3} \cdot FAT(i)$

IF .15 $\leq$ FAT(i) < .9, $HSLS(i) = \frac{44}{3} \cdot FAT(i) + 5.8$

IF .9 $\leq$ FAT(i), HSLS(i) = 310 · FAT(i) − 260.

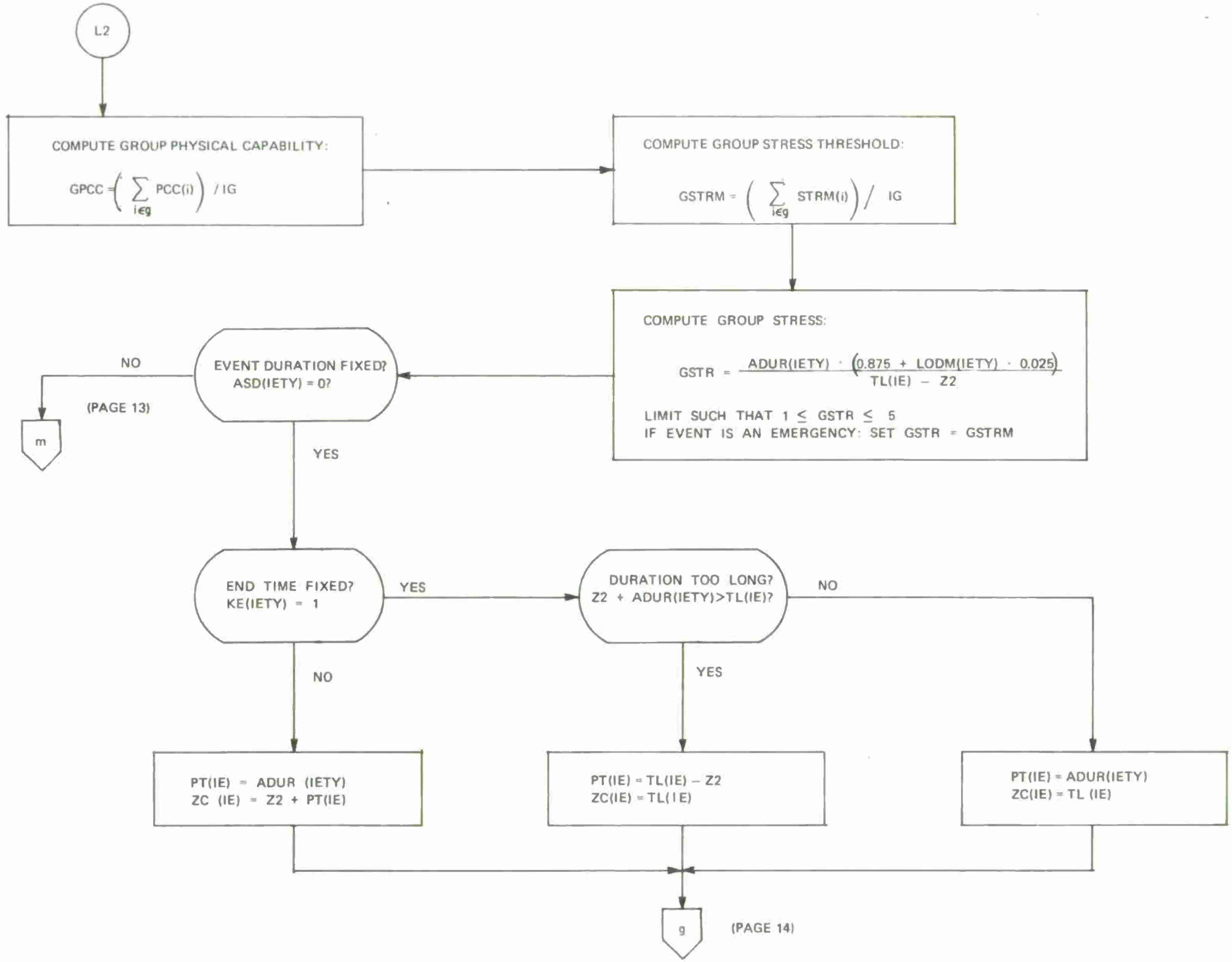
→ (L0) (PAGE 10)

↔ (X1)

ADJUST HOURS SINCE LAST SLEEP FOR EACH GROUP MEMBER

HSLS(i) = HSLS (i) + WH(i)

CALL SUBROUTINE FBUILD TO COMPUTE FATIGUE BUILDUP


L2
COMPUTE GROUP PHYSICAL CAPABILITY:
$GPCC = \left(\sum_{i \in g} PCC(i) \right) / IG$
COMPUTE GROUP STRESS THRESHOLD:
$GSTRM = \left(\sum_{i \in g} STRM(i) \right) / IG$
COMPUTE GROUP STRESS:
$GSTR = \frac{ADUR(IETY) \cdot (0.875 + LODM(IETY) \cdot 0.025)}{TL(IE) - Z2}$
LIMIT SUCH THAT $1 \leq GSTR \leq 5$
IF EVENT IS AN EMERGENCY: SET GSTR = GSTRM
EVENT DURATION FIXED?
ASD(IETY) = 0?
NO
(PAGE 13)
m
YES
END TIME FIXED?
KE(IETY) = 1
YES
DURATION TOO LONG?
Z2 + ADUR(IETY)>TL(IE)?
NO
NO
YES
PT(IE) = ADUR (IETY)
ZC (IE) = Z2 + PT(IE)
PT(IE) = TL(IE) – Z2
ZC(IE) = TL(IE)
PT(IE) = ADUR(IETY)
ZC(IE) = TL (IE)
g
(PAGE 14)

13

m

COMPUTE GROUP PERFORMANCE:

$$GPERF = \left(\sum_{i \in G} PERF(i) \right) / IG$$

COMPUTE GROUP ASPIRATION:

$$GASP = \left(\sum_{i \in G} CASP(i) \right) / IG$$

SELECT ONE OF FIVE CASES:

0. $|GASP - GPERF| \leq 0.02$
1. $GPERF < GASP$ and $GSTR < GSTRM$
2. $GPERF \geq GASP$ and $GSTR < GSTRM$
3. $GPERF < GASP$ and $GSTR \geq GSTRM$
4. $GPERF \geq GASP$ and $GSTR \geq GSTRM$

1: $PAF = -0.4\ (GASP - GPERF)$

2: FOR EACH MAN $i \in G$:
IF $PERF(i) > CASP(i)$,
$CASP(i) = CASP(i) + 0.1 \left(PERF(i) - CASP(i) \right) RY$
LIMIT SUCH THAT $CASP(i) \leq 1.0$

3: FOR EACH $i \in G$:
$CASP(i) = PERF(i)$
$PAF = 1 + 0.4\ (GASP - GPERF)$

4: $GSTR = 0.9 \cdot GSTRM$

COMPUTE PERFORMANCE TIME:

IF $GPCC < 1$, $SF = 2.0 - GPCC$
OTHERWISE $SF = 1.5 - (GPCC/2)$

$$GPACE = \left[\left(\sum_{i \in G} PACE(i) \right) IG \right] \cdot PAF \cdot SF \qquad \text{(GROUP PACE)}$$

$$V = e^{\left(\ln TEM2 + RD \sqrt{\ln TEM1} \right)} \text{ WHERE } TEM1 = 1 + \frac{ASD(IETY)^2}{ADUR(IETY)^2}$$

$$\text{AND } TEM2 = \frac{ADUR(IETY)}{\sqrt{TEM1}} \qquad \text{FOR REPAIR EVENTS}$$

$$V = ADUR(IETY) + RD \cdot ASD(IETY) \qquad \begin{cases} \text{FOR SCHEDULED EVENTS} \\ \text{AND EMERGENCIES} \end{cases}$$

IF $GSTR < GSTRM$:

$$PT(IE) = GPACE \cdot (1 - 2.35075t + 3.4722t^2 - 1.829t^3) \cdot V$$

$$\text{WHERE } t = \left(\frac{GSTR - 1}{GSTRM \cdot 1} \right)^3$$

IF $GSTRM \leq GSTR \leq GSTRM + 1$, $PT(IE) =$

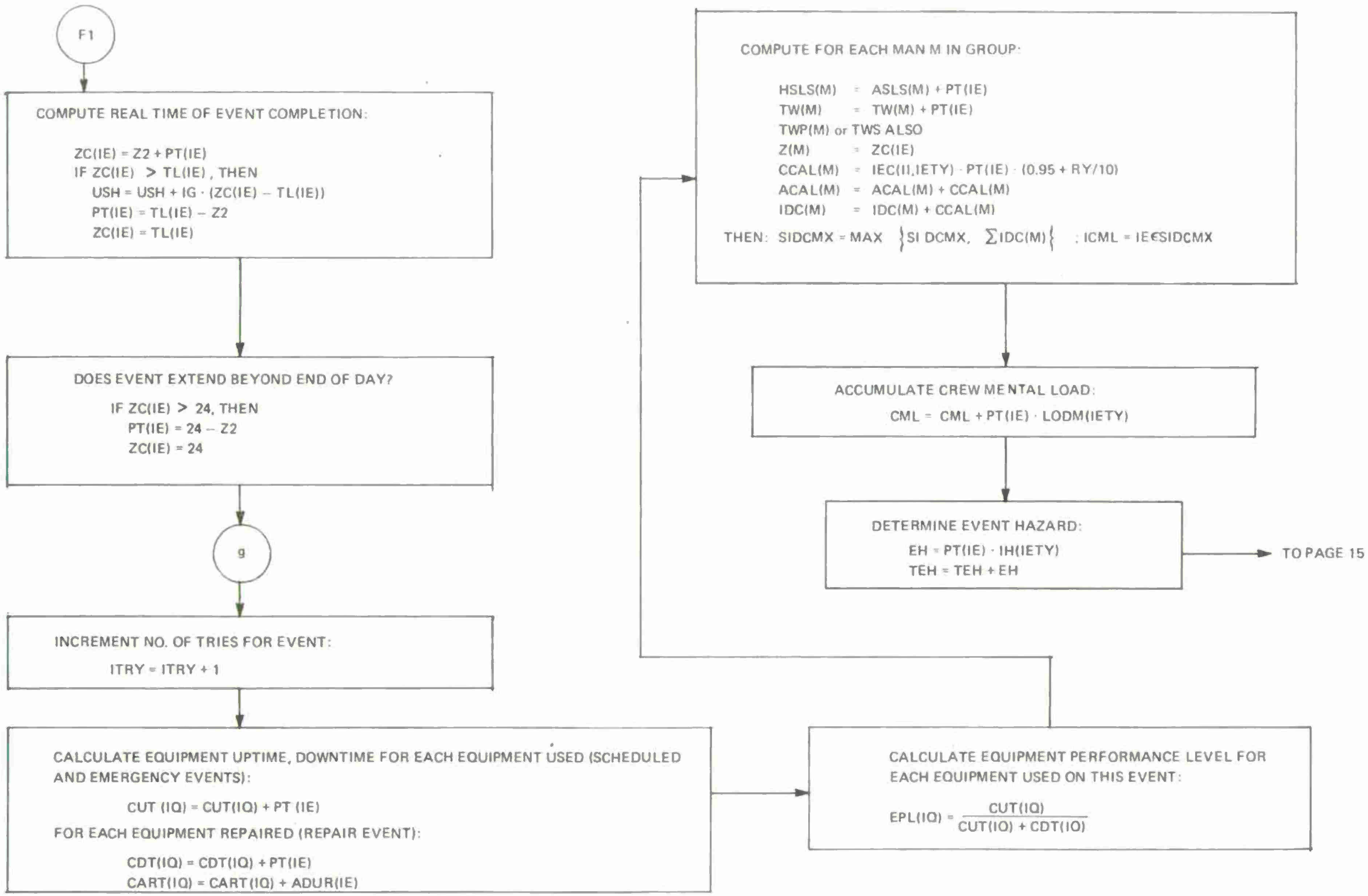
$$GPACE \cdot \left[V \left(2(GSTR - GSTRM) + 1 \right) - ADUR(IETY) \cdot (GSTR - GSTRM) \right]$$

OTHERWISE, $PT(IE) = GPACE \cdot \left(3.0V - ADUR(IETY) \right)$

LIMIT SUCH THAT $0 \leq PT(IE) \leq 4 ADUR(IETY)$

F1

(PAGE 14)


F1
COMPUTE REAL TIME OF EVENT COMPLETION:
ZC(IE) = Z2 + PT(IE)
IF ZC(IE) > TL(IE), THEN
USH = USH + IG · (ZC(IE) – TL(IE))
PT(IE) = TL(IE) – Z2
ZC(IE) = TL(IE)
DOES EVENT EXTEND BEYOND END OF DAY?
IF ZC(IE) > 24, THEN
PT(IE) = 24 – Z2
ZC(IE) = 24
g
INCREMENT NO. OF TRIES FOR EVENT:
ITRY = ITRY + 1
CALCULATE EQUIPMENT UPTIME, DOWNTIME FOR EACH EQUIPMENT USED (SCHEDULED AND EMERGENCY EVENTS):
CUT (IQ) = CUT(IQ) + PT (IE)
FOR EACH EQUIPMENT REPAIRED (REPAIR EVENT):
CDT(IQ) = CDT(IQ) + PT(IE)
CART(IQ) = CART(IQ) + ADUR(IE)
CALCULATE EQUIPMENT PERFORMANCE LEVEL FOR EACH EQUIPMENT USED ON THIS EVENT:
EPL(IQ) = CUT(IQ) / (CUT(IQ) + CDT(IQ))
COMPUTE FOR EACH MAN M IN GROUP:
HSLS(M) = ASLS(M) + PT(IE)
TW(M) = TW(M) + PT(IE)
TWP(M) or TWS ALSO
Z(M) = ZC(IE)
CCAL(M) = IEC(II,IETY) · PT(IE) · (0.95 + RY/10)
ACAL(M) = ACAL(M) + CCAL(M)
IDC(M) = IDC(M) + CCAL(M)
THEN: SIDCMX = MAX {SI DCMX, ΣIDC(M)} ; ICML = IE∈SIDCMX
ACCUMULATE CREW MENTAL LOAD:
CML = CML + PT(IE) · LODM(IETY)
DETERMINE EVENT HAZARD:
EH = PT(IE) · IH(IETY)
TEH = TEH + EH
TO PAGE 15

FROM PAGE 14

COMPUTE PERFORMANCE ADEQUACY (PA):

$$ES = \left(\frac{1 - BE}{GSTRM - 1}\right) \cdot GSTR + BE \qquad \text{if } GSTR < GSTRM$$

$$= \frac{5 - GSTR}{5 - GSTRM} \qquad \text{if } GSTRM \leq GSTR < 5$$

$$= 0 \qquad \text{if } GSTR > 5$$

$$EC = \left[2TPCOM(LI) + \sum_{i \in G} TPCOM(i)\right] / (IG + 2) \text{ if } ITRY = 1$$

(REPLACE TPCOM WITH TSCOM FOR MEN SELECTED TO WORK IN SECONDARY FIELD)

$$= EC + 0.2 \quad \text{IF} \quad ITRY = 2 \quad (0 \leq EC \leq 1.0)$$

$$EF = CPCC \quad \text{if } GPCC < 1$$

$$= 1.0 \text{ Otherwise}$$

$$EA = \left\{ 2\,CASP(LI) + \sum_{i \in G} CASP(i) \right\} / (IG + 2)$$

$$PA = \left(\frac{3\,EC \cdot (ES + EF + EA) + ES \cdot (EF + EA) + EF \cdot EA}{12}\right)^{1/2}$$

DEGRADE PERFORMANCE ADEQUACY IF DURATION TARGET IS EXCEEDED ON REPAIR OF EMERGENCY

IF EVENT IS A REPAIR AND PT (IE) > DTR(IQ), THEN

$$PA = PA \frac{DTR\ (IQ)}{PT\ (IE)}$$

IF EVENT IS AN EMERGENCY AND PT(IE)   DTR(K), THEN

$$PA = PA \frac{DTE(K)}{PT(IE)}$$

SUM PERFORMANCE ADEQUACY $APA = APA + PA$

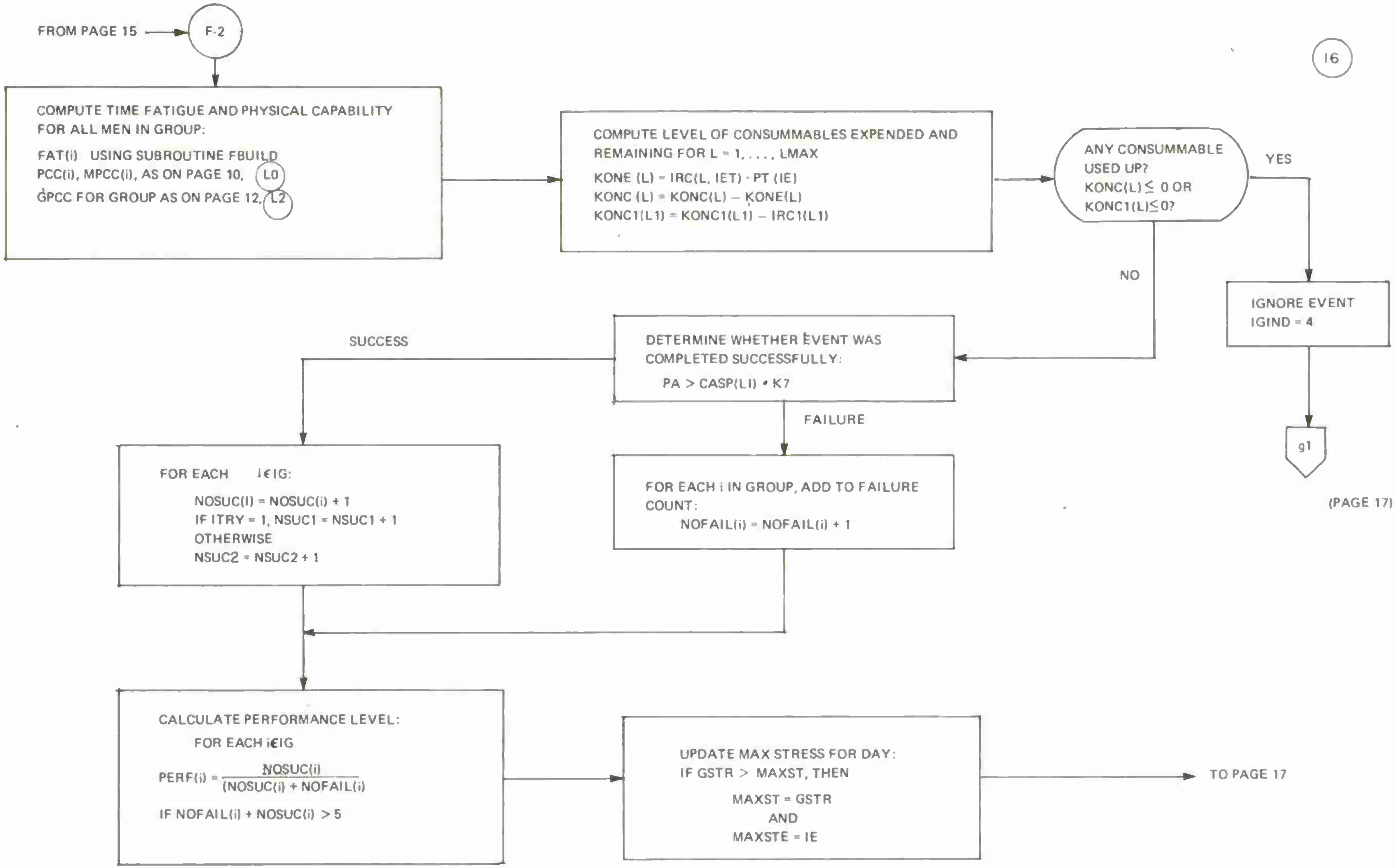
CALCULATE AND SUM EVENT PERFORMANCE EFFICIENCY

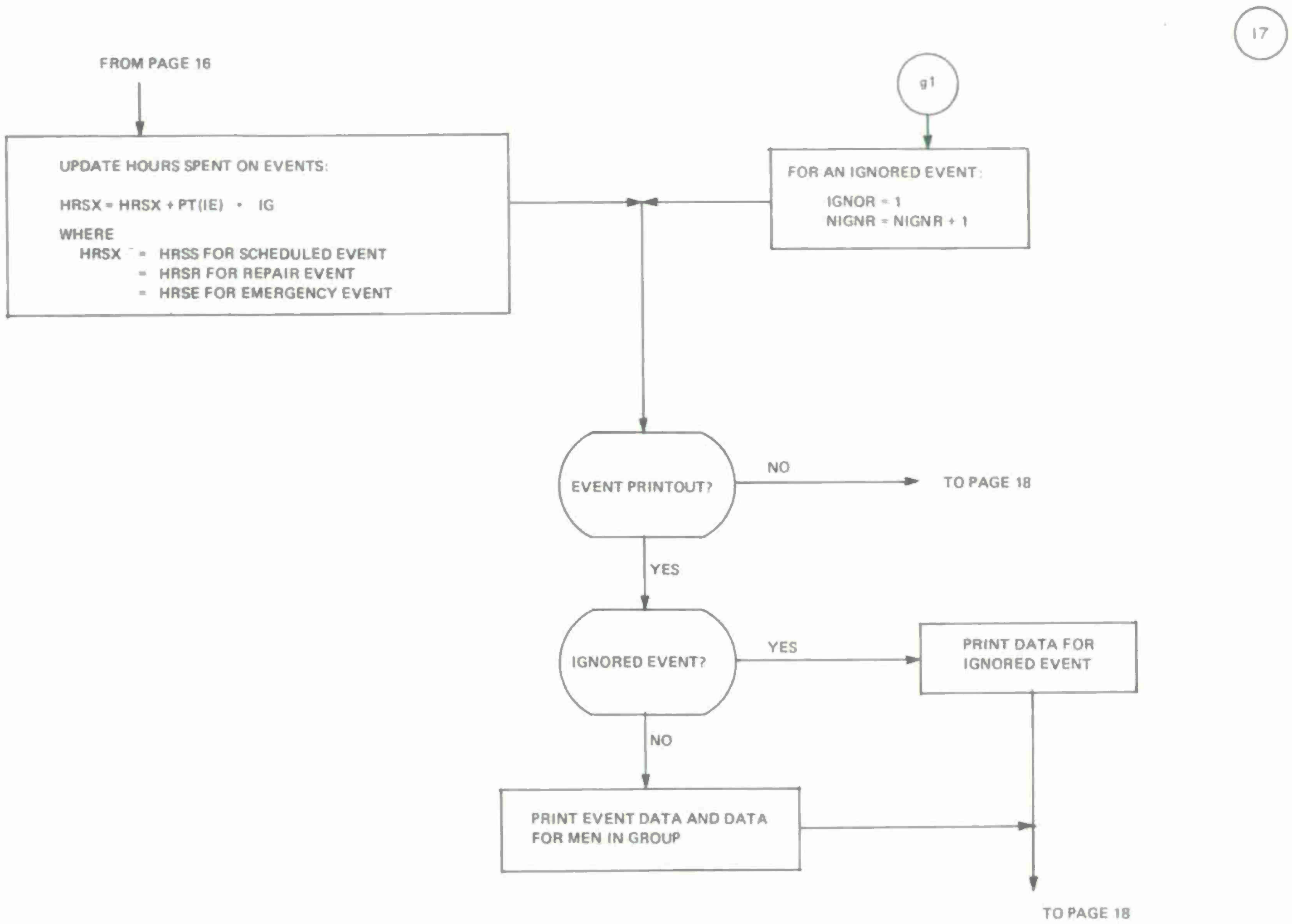
$$SEF = \frac{PA \cdot IESS(IE)}{CASP(LI) \cdot K7} + SEF$$

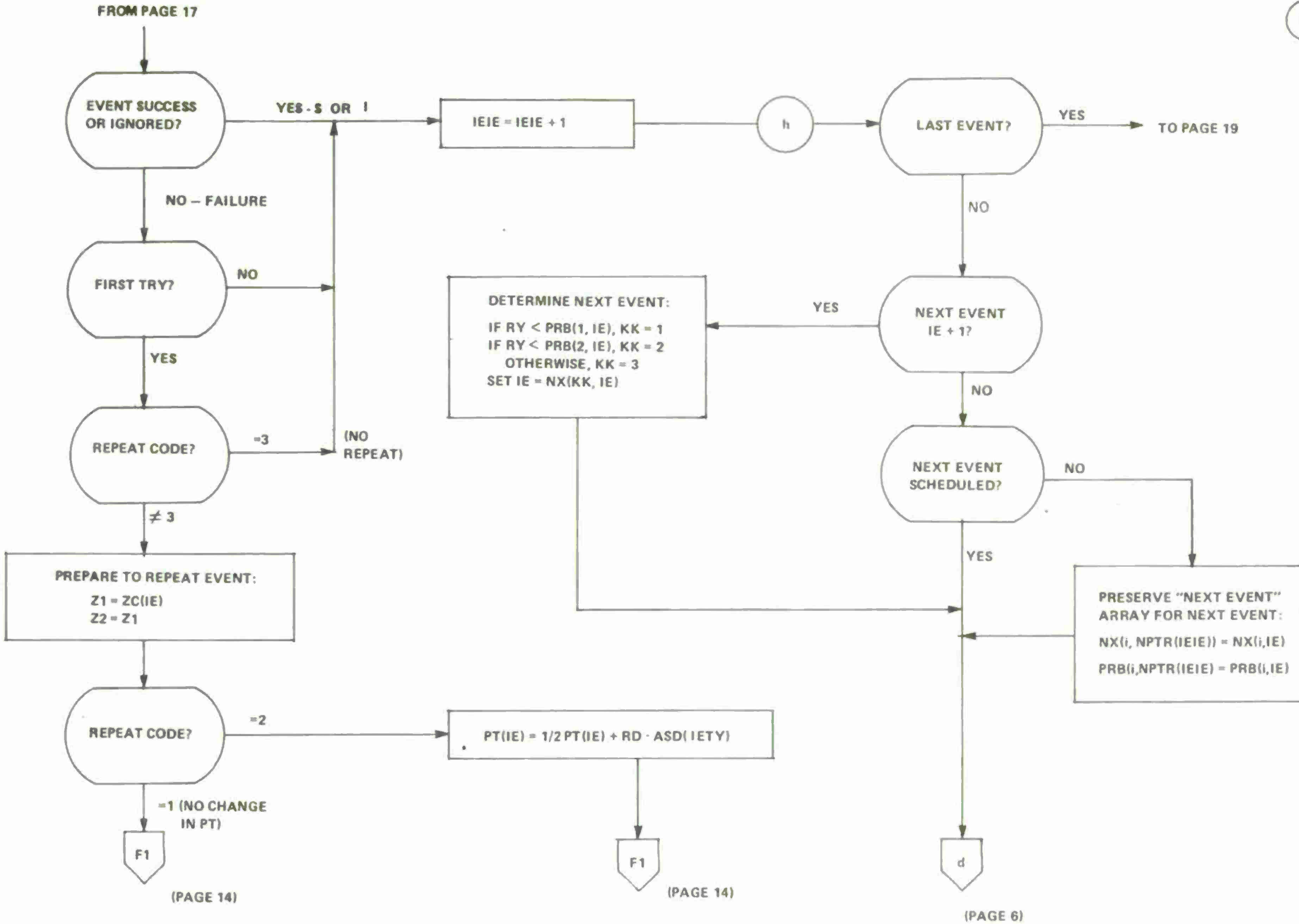
SUM EVENT ESSENTIALITY VALUES

$$ISIE = ISIE + IESS(IE)$$

TO PAGE 16


FROM PAGE 15
F-2
COMPUTE TIME FATIGUE AND PHYSICAL CAPABILITY FOR ALL MEN IN GROUP:
FAT(i) USING SUBROUTINE FBUILD
PCC(i), MPCC(i), AS ON PAGE 10, L0
GPCC FOR GROUP AS ON PAGE 12, L2
COMPUTE LEVEL OF CONSUMMABLES EXPENDED AND REMAINING FOR L = 1, . . . , LMAX
KONE (L) = IRC(L, IET) · PT (IE)
KONC (L) = KONC(L) – KONE(L)
KONC1(L1) = KONC1(L1) – IRC1(L1)
ANY CONSUMMABLE USED UP? KONC(L) ≤ 0 OR KONC1(L) ≤ 0?
YES
NO
IGNORE EVENT
IGIND = 4
g1
(PAGE 17)
DETERMINE WHETHER EVENT WAS COMPLETED SUCCESSFULLY:
PA > CASP(LI) • K7
SUCCESS
FAILURE
FOR EACH i ∈ IG:
NOSUC(I) = NOSUC(i) + 1
IF ITRY = 1, NSUC1 = NSUC1 + 1
OTHERWISE
NSUC2 = NSUC2 + 1
FOR EACH i IN GROUP, ADD TO FAILURE COUNT:
NOFAIL(i) = NOFAIL(i) + 1
CALCULATE PERFORMANCE LEVEL:
FOR EACH i ∈ IG
PERF(i) = NOSUC(i) / (NOSUC(i) + NOFAIL(i))
IF NOFAIL(i) + NOSUC(i) > 5
UPDATE MAX STRESS FOR DAY:
IF GSTR > MAXST, THEN
MAXST = GSTR
AND
MAXSTE = IE
TO PAGE 17


17
FROM PAGE 16
UPDATE HOURS SPENT ON EVENTS:
HRSX = HRSX + PT(IE) · IG
WHERE
HRSX = HRSS FOR SCHEDULED EVENT
= HRSR FOR REPAIR EVENT
= HRSE FOR EMERGENCY EVENT
g1
FOR AN IGNORED EVENT:
IGNOR = 1
NIGNR = NIGNR + 1
EVENT PRINTOUT?
NO
TO PAGE 18
YES
IGNORED EVENT?
YES
PRINT DATA FOR IGNORED EVENT
NO
PRINT EVENT DATA AND DATA FOR MEN IN GROUP
TO PAGE 18


FROM PAGE 17
EVENT SUCCESS OR IGNORED?
YES - S OR I
IEIE = IEIE + 1
h
LAST EVENT?
YES
TO PAGE 19
NO – FAILURE
NO
FIRST TRY?
NO
DETERMINE NEXT EVENT:
IF RY < PRB(1, IE), KK = 1
IF RY < PRB(2, IE), KK = 2
OTHERWISE, KK = 3
SET IE = NX(KK, IE)
YES
NEXT EVENT IE + 1?
YES
NO
REPEAT CODE?
=3
(NO REPEAT)
NEXT EVENT SCHEDULED?
NO
≠ 3
YES
PREPARE TO REPEAT EVENT:
Z1 = ZC(IE)
Z2 = Z1
PRESERVE "NEXT EVENT" ARRAY FOR NEXT EVENT:
NX(i, NPTR(IEIE)) = NX(i,IE)
PRB(i,NPTR(IEIE) = PRB(i,IE)
REPEAT CODE?
=2
PT(IE) = 1/2 PT(IE) + RD · ASD(IETY)
=1 (NO CHANGE IN PT)
F1
(PAGE 14)
F1
(PAGE 14)
d
(PAGE 6)

FROM PAGE 18

COMPUTE AVERAGE PHYSICAL WORKLOAD AND PRIMARY COMPETENCE:

FOR M = 1, 2, . . . , IC

$$APW(M) = \frac{IDC(M) \cdot TW(M)}{CAL(M) \cdot WORK1}$$

IF PCOM(M > CASP(N), THEN

$$PCOM(M) = PCOM(M) + \left[CASP(M) - PCOM(M)\right] \cdot NU(M) \cdot 0.0017$$

COMPUTE CURRENT CREW COMPETENCE:

$$CCC = \left[\sum_{i=1}^{IC} PCOM(i)\right] \Big/ IC$$

COMPUTE AVERAGE EQUIPMENT PERFORMANCE LEVEL:

$$AEPL = \left[\sum_{i=1}^{IQMAX} EPL(i)\right] \Big/ IQMAX$$

COMPUTE EQUIPMENT PERFORMANCE EFFICIENCY:

$$EPEFF = AEPL \cdot \left[\sum_{IQ=1}^{IQMAX} CART(IQ)\right] \Big/ \sum_{IQ=1}^{IQMAX} CDT(IQ)$$

$$0 \leq EPEFF \leq 1.0$$

COMPUTE DAILY PERFORMANCE EFFICIENCY:

$$PEFF = \frac{SEE}{ISIE} \left(1 - \frac{USHT}{WORK1 \cdot IC}\right) \left(1 - \frac{NIGNR}{NTE}\right)$$

TO PAGE 20

FROM PAGE 19

COMPUTE SYSTEM RELIABILITY LEVEL:

$$SRL = 0.7 + 8.571 \left[\left(\sum_{M=1}^{IC} PERF\ (M) \right) - 0.65 \right] \left[AEPL - 0.9 \right]$$

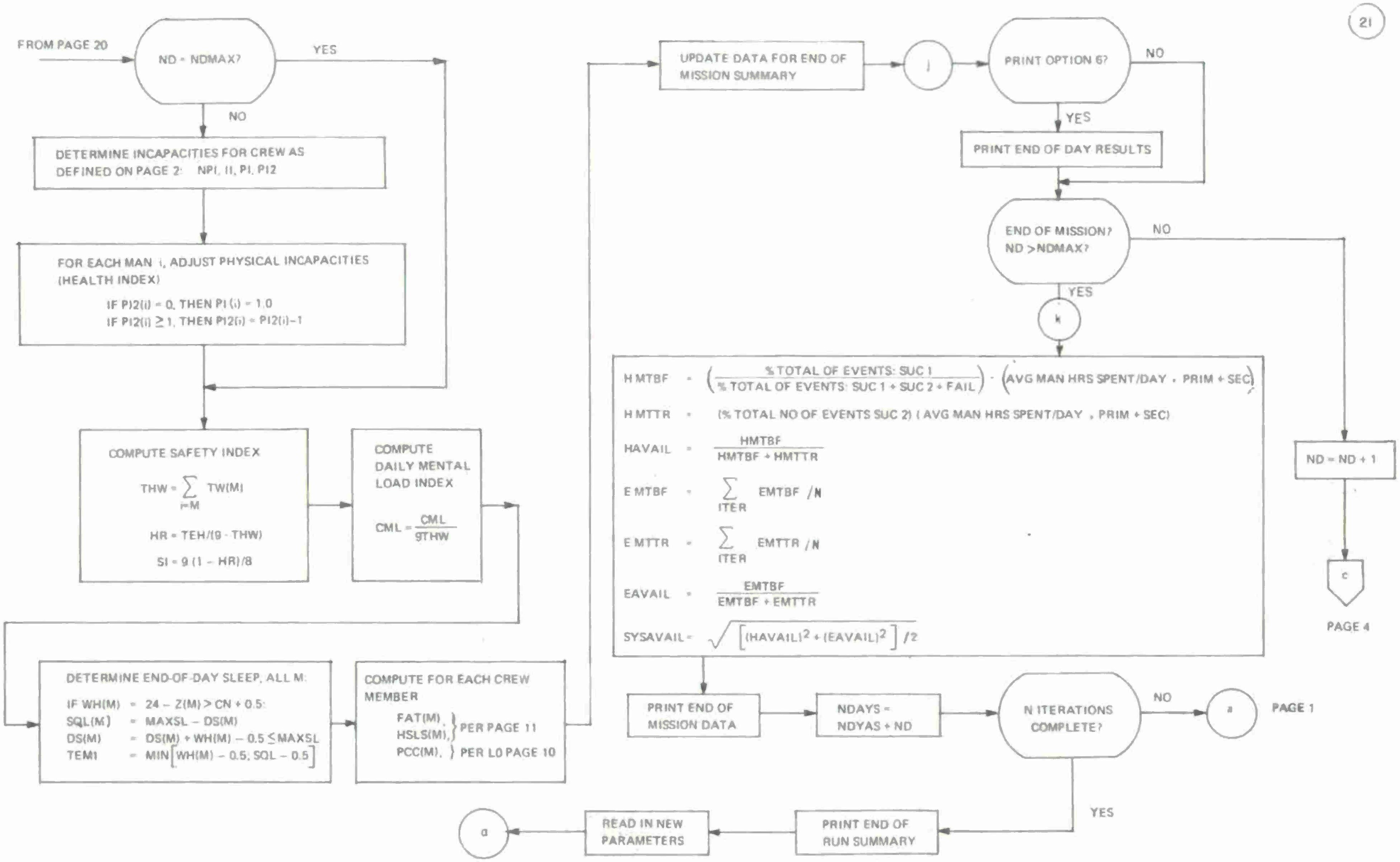
COMPUTE SYSTEM PERFORMANCE LEVEL

$$SPL = 0.7 + 8.571 \left[PEFF - 0.65 \right] \left[EPEFF - 0.9 \right]$$

COMPUTE GENERAL SYSTEM MEASURE

$$SGEM = \sqrt{\frac{(SRL - 0.7)^2 + (SPL - 0.7)^2}{2}}$$

TO PAGE 21



21
FROM PAGE 20
ND = NDMAX?
YES
NO
DETERMINE INCAPACITIES FOR CREW AS DEFINED ON PAGE 2: NPI, II, PI, PI2
FOR EACH MAN i, ADJUST PHYSICAL INCAPACITIES (HEALTH INDEX)
IF PI2(i) = 0, THEN PI (i) = 1.0
IF PI2(i) ≥ 1, THEN PI2(i) = PI2(i)−1
COMPUTE SAFETY INDEX
THW = Σ TW(M)
HR = TEH/(9 − THW)
SI = 9 (1 − HR)/8
COMPUTE DAILY MENTAL LOAD INDEX
CML = CML / 9THW
DETERMINE END-OF-DAY SLEEP, ALL M:
IF WH(M) = 24 − Z(M) > CN + 0.5:
SQL(M) = MAXSL − DS(M)
DS(M) = DS(M) + WH(M) − 0.5 ≤ MAXSL
TEM1 = MIN [WH(M) − 0.5; SQL − 0.5]
COMPUTE FOR EACH CREW MEMBER
FAT(M), HSLS(M), PER PAGE 11
PCC(M), PER LO PAGE 10
UPDATE DATA FOR END OF MISSION SUMMARY
j
PRINT OPTION 6?
NO
YES
PRINT END OF DAY RESULTS
END OF MISSION? ND > NDMAX?
NO
YES
k
HMTBF = (% TOTAL OF EVENTS: SUC 1 / % TOTAL OF EVENTS: SUC 1 + SUC 2 + FAIL) · (AVG MAN HRS SPENT/DAY · PRIM + SEC)
HMTTR = (% TOTAL NO OF EVENTS SUC 2) (AVG MAN HRS SPENT/DAY · PRIM + SEC)
HAVAIL = HMTBF / HMTBF + HMTTR
EMTBF = Σ ITER EMTBF /N
EMTTR = Σ ITER EMTTR /N
EAVAIL = EMTBF / EMTBF + EMTTR
SYSAVAIL = √[(HAVAIL)² + (EAVAIL)²] /2
ND = ND + 1
c
PAGE 4
PRINT END OF MISSION DATA
NDAYS = NDYAS + ND
N ITERATIONS COMPLETE?
NO
a
PAGE 1
YES
PRINT END OF RUN SUMMARY
READ IN NEW PARAMETERS
a

173

SUBROUTINE FBUILD (HSLS)
COMPUTE FATIGUE BUILDUP (FAT(M)) FOR EACH M:
FAT(M) = 0.01875 . HSLS(M) − RY · 0.2 if $0 \leq$ HSLS(M) < 8
FAT(M) = (15 · HSLS(M) − 109)/220 + RY · 0.2 if $8 \leq$ HSLS(M) < 19
FAT(M) = (HSLS(M) + 229)/310 + RY · 0.2 if HSLS(M) $\geq$ 19
$0 \leq$ FAT(M) ≤ 1

SUBROUTINE PSCAP: COMPUTE PRIMARY AND SECONDARY COMPETENCE (IAA, PCDUM, PSCOM)
CALCULATE PRIMARY AND SECONDARY COMPETENCES PERFORM STEPS 1, 2, 3 FOR i = 1, 2, 3, AND 4:
1. L(1) = IAA(i) · PPFQ L(2) = IAA(i) · PPMQ L(3) = IAA(i) · PPUQ
2. IF $\sum$ L(j) $\neq$ IAA(i), ROUND UP EACH L(j) IF EQUALITY IS NOT OBTAINED, ADD 1 TO EACH L(j), CONSIDERING THE LARGEST L(j) FIRST, UNTIL EQUALITY IS OBTAINED
3. ASSIGN THE FIRST L(i) MEN WITH ICE(M) = i PCOM(M) = .95 + RD · 0.03 FOR THE NEXT L(2) MEN WITH ICE(M) = i PCOM(M) = .75 + RD · 0.03 FOR THE NEXT L(3) MEN WITH ICE(M) = i PCOM(M) = .60 + RD · 0.03
4. REPEAT THIS PROCESS, REPLACING PCOM(M) WITH SCOM(M) AND PPFQ, PPMQ, PPUQ WITH SPFQ, SPMQ, SPUQ

APPENDIX D

Program Organization

APPENDIX D
COMPUTER PROGRAM ORGANIZATION

The Computer Program

The program for the model was given the name P420 and was prepared in the widely accepted FORTRAN IV programming language. All runs reported were made on the Honeywell 635 computing system.

The H-635 is a 36 bit word machine with cycle time of one microsecond. The ISM model requires 32k words of core memory storage to compile and execute where k = 1024.

A page-heading subroutine, available at most computer installations, and two random number generators are the only non-standard routines which would require special consideration when executing the simulation program at other facilities. The program was prepared with computer independence in mind so that converting the P420 program to FORTRAN for another large scale computer should require little more than replacing control cards and recompiling on the new computer.

The model divided into a executive program (XMAIN), input and output routines, and several supporting subroutines, and several supporting subroutines. In general terms, the executive performs the following functions:

a) Performs all initializations
b) Calls for parameter and personnel data from input routine
c) Determines crew characteristics
d) Calls for emergency and equipment repair event data and determines when in mission these events are to be simulated
e) Calls for scheduled event data for each day from input routine
f) Determines order for events to be simulated for the day
g) Selects crew for each event
h) Simulates crew performance and evaluates same

i) Allows for second attempt of "failed" event
j) Prints results for each event (optional)
k) Determines next event
l) At end of day, summarizes events for day and calls output routine to print daily results
m) At end of iteration, calls output routine to print iteration summary
n) At end of mission, calls output routine to print mission summary

The detailed event results (item j above) will be printed on events for which the event and day numbers exceed the values of IND(5) and IND(4) respectively (see Appendix A, Table A-7).

The input routine (INPT1) is responsible for accepting the simulation input data and, after verifying that each input section contained the proper number of data items, passes the data to the executive. Optionally, a complete listing of all input data can be printed by the input routine (see IND(1) Appendix A Table A-7). The parameters are unconditionally printed. If a section of the input file does not contain the proper number of data items, an appropriate message together with all of the data or that type (e.g., personnel data) is printed for review and the program halts after checking the remaining input sections.

There are four entries to the input subroutine (OUTP1). The first entry is used when a listing and summary of the crew characteristics is requested. This output occurs, when requested by print option 2, at the beginning of each iteration. This option is dependent on IND(2) (see Appendix A, Table A-7).

The second entry provides for summarizing the results of a days simulation. A printed listing of these data may or may not be effected, depending upon print option 6. The end of day results will be recorded on such iteration on those days for which the day number exceeds the value of IND(6).

The third entry in the output routine unconditionally prints the (see example Table 2-5) report summarizing the data obtained at the end of each iteration of the simulated mission. Table 206 presents this format.

The fourth, and final, entry unconditionally summarizes and prints data obtained at the end of each run of N iterations as shown in Table .

The supporting subroutines, also coded in FORTRAN IV, are FBUILD, IPUYSN, and PSCAP. The function of FBUILD is to compute fatugue buildup for the men in the crew; IPUYSN generates random numbers with a poisson distribution; and PSCAP determines primary and secondary competence levels for each man in the crew.

The Input Card Deck

The card deck organization for execution of the program on the H635 is shown below:

Column 1	Column 8	Column 16
$	SNUMB	XXXXX
$	IDENT	XXXXX,——
	OBJECT DECKS: XMAIN, OUTP1, INPT1, IPUYSN, FBUILD, PSCAP	
$	EXECUTE	
$	LIMITS 05, 32k, 2000	
$	TAPE 10, X1D,, XXXXX,,——	
$	FILE 12, X6R, 2R	
$	INCODE (OPTION)	
	input data for all formats	
$	ENDJOB	

Figure D-1 P420 Deck Set-Up

The

The five digit number in the first card represents a run number used by the computation center to identify the run. The 5 digit number in the second card represents a charge number or accounting code. On the LIMITS card, the numbers indicate the maximum length processor time core memory (K= 1024) and print lines on a given run. The run will be terminated if any of these conditions is noted. On the TAPE card, the numbers indicate the logical unit number, the channel number (D= dismantle after run), and the physical tape reel numbers. The options on the INCODE card are either IBMF (FORTRAN code prepared on the Model 026 Keypunch) or IBMEL (extended language code, prepared on the Model 029 Keypunch).

At many installations, both the $SNUMB and $IDENT cards are prepared by the operations personnel. The $TAPE card is required only on runs requiring more than one iteration or for runs employing the tape input option.

When a simulation with multiple iterations is completed a tape containing a large portion of the input data has been created. This tape may be used in subsequent simulations by choosing the tape option for input. The tape contains all the input following the $PERSNL data group. This means that if the print option was in effect (IND(1)$\neq$ 0) when the tape was created, the descriptors for the equipment repairs and emergency events are also on the tape. Hence the user must enact the print option when employing that data tape. Failure to do so will cause improper reading of records and the program will abort.

Program Timing

The recompilation time on the H-635 is from one to two minutes depending on the extent of the programs compiled. Execution time is, of course dependent on the simulation input data involved. The following execution time estimates are examples from runs made with the mission data described in Chapter III. A run of 10 iterations during which recording was made for summaries only consumed about .020 seconds per event. A run in which all detail event output was recorded consumed .059 seconds per event or about 1.2 minutes for a 5 iteration run. As another example, a two mission case each with 5 iterations of 4 days with full detail recordings of all events took 146 seconds of processor time. This corresponds to 0.056 seconds of processor time per event.

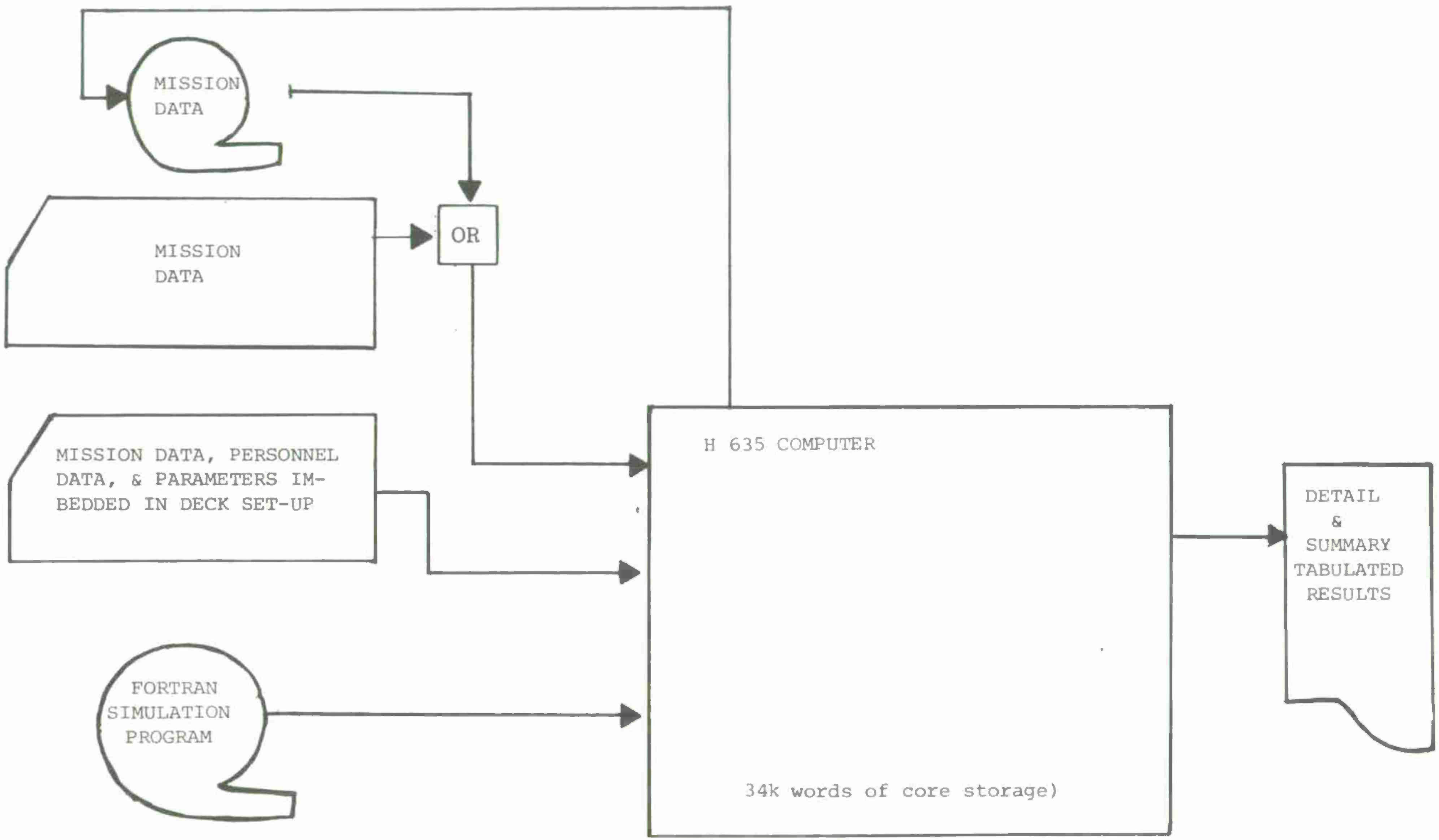


Figure D-2

Computer Simulation System

APPENDIX E

Computer Program*

* This computer program, like all simulation programs, is evolutionary. The program presented in Appendix E represents the status of the simulation model program as of November 22, 1974.

```
CXMAIN         XMAIN
      COMMON/PRSNEL/WT,SIGWT,PPFQ,PPMQ,PPUQ,SPFQ,SPMQ,SPUQ,
     1MPI,PID,ZPC,PTT(10,10),MEN(10,4),NDS,IDS(6,20)
      COMMON/IPARAM/APST,WORK1,WORK2,SLEEP,CN,MAXSL,TFAT,ACP,
     1CALRY,PWRRT,K7,K1,BE,AASP,KON(10),KONT(10,10),KON1(10),
     2 KONT1(10,10),SESTA(20),RELI(4),N,IET,IND(7),NDMAX
      COMMON/EQREVNT/ IDF(30),RELH(30),DTR(570),TUI(30),IRE(30)
      COMMON/EEMER/ART(10),ASDE(10),DTE(10),IESSE(10) ,NREQE(10,10),
     1 LODME(10),IRCE(10,10),IRCE1(10,10),TSE(10),TSE1(10),IHE(10),
     1 IECE(10,10),DTBE(10),NDBE(10)
      COMMON/ETYPE/ADUR,ASD,IESS,NREQ(10),LODM,KE,INT,IRC(10),IRC1(10),
     1 IH,IEC(10),NTOR,IOR(6),ICLASS
      COMMON/SEVENT/IETYP(570),TL(570),ST(570),EDCV(3,570),IPE(570),
     1 TS(570),TS1(570),NX(8,570),RTU(570),IFOI(570),IEFN(570),NIF(570),
     2  IEDC(3,570),PRB(3,570),NOSE,NEORE,NEME,DI(9)
      COMMON/QCOM/PCOM(20),SCOM(20),IPS(20),ISS(20),TPCOM(20),TSCOM(20)
       COMMON/OPP1/ IAA(4),PC(20),PACE(20),ASP(20),HSLS(20),PI(20)
     1,PI2(20),ICE(20)
       COMMON/OPP2/ TW(20),TWP(20),TWS(20),DS(20),APW(20),PCC(20),
     1               CASP(20),IDC(20),        NSUC1,NSUC2,NFALE,NIGNR,
     2 KONC(10),KONC1(10), SI,CML,ND,ITER,NDAYS,MPCC(20),FAT(20)
     3 ,STRM(20),CAL(20),PWR(20),CCAL(20),NU(20),PERF(20),NPRFM(4)
     4 ,APA,SFDIFF,CLSDTA(10,40)
       COMMON/OPP3/IC,FLIC,NREPT,HRSE,HRSR,HRSS,PEFF,
     1 MAXST,MAXSTE,USHT,NR,NTE,NE,TEH,CMLMX,ICML,SIDCMX,IDCMX,ICSS
      COMMON/OPP4/EPL(30),CDT(30),CART(30),CUT(30),
     1 AEPL,EPEFF,EMTBF,EMTTR,SRL,SPL,SGEM
      INTEGER TS,TS1,RTU,TSE,TSE1,TSR,TSR1
      INTEGER PI2,PTR(240),IOIF(10)
       REAL KONC,NOSUC(20),NOFAIL(20),IDC,KONE(20),MPCC     ,MAXST,NU
      REAL MPI,MAXSL,K7,K1,IEC,LODM,IH,IRC,KON,KON1,KONT,KONT1
       REAL IECE,IHE,IRCE,LODME,IST
      DIMENSION NPTR(580),ADURIO(55)
     1 ,KONE1(20)
       DIMENSION PSCOM(40),IPSS(40),PCDUM(6),TPSCOM(40)
       EQUIVALENCE (PCDUM,PPFQ),(PSCOM,PCOM),(IPSS,IPS),(TPSCOM,TPCOM)
      EQUIVALENCE (ADUR,ADURIO)
      DIMENSION NS(20),IDE(10),
     1                    Z(20),ZC(570),IEVENT(570),NREQT(10),MAVAIL(20),
     2              TAVAIL(20),MA(20,10),ITYPE(20),MAT(20),WH(20),ACAL(20),
     3 PT(570),TITLE(9)
      DIMENSION MCHSN(20), INVS(570),USH(6)
      DIMENSION HEADR(12)
      DATA HEADR(1)/72H APPLIED PSYCHOLOGICAL SERVICES      WAYNE, PENNA
     1,       ARTHUR I. SIEGEL/
       DATA TITLE/6HSCHEDU,6HLED EV,6HENT   ,6HREPAIR,6H FAMIL,
     16HY      ,6HEMERGE,6HNCY EV,6HENT   /
       DATA YU,ESSS,PEA/6H     U,6H     S,6H     P/
       DATA STAR,BLANK/6H     *,6H      /
      FUNC(A,B, D) = (A + (A*B)/4.) *  D
      CALL RANSIZ(12,55)
      READ(5,9050) NKASES
```

```
      KASE = 0
   10 KASE = KASE+1
      IF(KASE .GT. NKASES)  CALL EXIT
       READ(5,9045) HEADR
 9045  FORMAT(12A6)
      CALL SPGHDR(HEADR)
       LMAX=10
      LMAX1=10
       NTMAX=10
        ITER=0
      NKOUNT = 0
      READ(5,9050) ITAP,NDMAX
      CALL XXIN
   50   ITER=ITER+1
      ITAP = ITAP+1
      NDAYS = 0
 9050 FORMAT (2I3)
      CALL INPUT(ITAP,KASE)
       KMAX=NEME
       IQMAX=NEQRE
       IEMAX=NOSE+NEQRE+NEME
C***COUNT THE CREW FOR EACH ECHELON AND ASSIGN
C***EACH MAN A CREW ECHELON
      IC = 0
      DO 110 I = 1,4
      IAA(I) = 0
      DO 100 J = 1,NTMAX
  100 IAA(I) = IAA(I)+MEN(J,I)
  110 IC = IAA(I)+IC
      FLIC = IC
      II = 1
      JJ = 0
      DO 120 I = 1,4
      JJ = IAA(I)+JJ
      IF (JJ.LT.II) GO TO 120
      DO 115 J = II,JJ
  115 ICE(J) = I
      II = JJ+1
  120 CONTINUE
C***ASSIGN PRIMARY SPECIALTIES
      M = 1
      DO 160 J = 1,4
      DO 160 I = 1,NTMAX
      II = MEN(I,J)
      IF (II.EQ.0) GO TO 160
      DO 155 K = 1,II
      IPS(M) = I
  155 M = M+1
  160 CONTINUE
C***ASSIGN SECONDARY SPECIALTIES
      DO 220 I = 1,IC
      II = IPS(I)
      TEM1 = UNIFM1(0.0)
      TEM1 = TEM1*PTT(NTMAX,II)
      DO 210 J = 1,NTMAX
      IF (PTT(J,II).LT.TEM1) GO TO 210
```

```
      ISS(I) = J
      GO TO 220
  210 CONTINUE
  220 CONTINUE
C***PC,CAL,PWR,PACE,ASP,HSLS,FAT,STRM  FOR
C***EACH MAN
      DO 300 I = 1,IC
      TEM1 = DNORM1(0.0)
       PC(I)=(WT+TEM1*SIGWT)/WT
      CAL(I) = PC(I)*CALRY
      PWR(I) = PC(I)*PWRRT
      PACE(I) = ACP + DNORM1(0.0) * 0.11
      ASP(I) = AMIN1(AASP+AASP*DNORM1(0.0)/10.0,1.0)
      HSLS(I) = SLEEP+DNORM1(0.0)*SLEEP*0.25
       FAT(I)=FBUILD(HSLS(I))
  300 STRM(I) = APST+DNORM1(0,0)*APST/6.0
C***CALCULATE PRIMARY AND SECONDARY COMPETANCE
C***FOR EACH MAN AND CCI=INITIAL CREW COMPETANCE
      CALL PSCAP(IAA,PCDUM, PSCOM)
      CCI = 0.0

      DO 360 I = 1,IC
  360 CCI = CCI+ PCOM(I)
      CCI = CCI/FLIC
C***CALCULATE PHYSICAL INCAPACITIES
  365 DO 370 I = 1,IC
       PI(I)=1.0
  370  PI2(I)=0
      NPI = IPUYSN(FLIC/MPI)
      IF (NPI.EQ.0) GO TO 390
      DO 380 I = 1,NPI
      II = UNIFM1(0.0)*FLIC
      PI(II) = 0.2*UNIFM1(0.0)+0.75
  380 PI2(II) = IPUYSN(PID)
  390 CALL OUTP1
C***FIRST DAY OF ITERATION**-INITIALIZATIONS
  550 ND = 1
      DO 560 I = 1,KMAX
  560 IDE(I) = 0
      DO 570 I = 1,IQMAX
  570 IDF(I) = 0
      DO 580 I = 1,LMAX
  580 KONC(I) = KON(I)
      DO 585 I =1,LMAX1
  585 KONC1 (I) = KON1 (I)
      DO 590 I = 1,IC
      NS(I) = 0
      ACAL(I) = HSLS(I)*CAL(I)/24.0
      CASP(I) = ASP(I)
       PERF(I)=ASP(I)
      NOSUC(I) = 0.0
  590 NOFAIL(I) = 0.0
C
C     DETERMINE DAY OF OCCURRENCES OF NEXT FAILURES AND EMERGENCIES FOR
C     FAILURE AND EQUIPMENT
C
      DO 605 I = 1,IQMAX
```

```
      II =            RELH (I) * ALOG(UNIFM1(0.0)) - 0.5
      IF(II.EQ.0)II=-1
  605 IDF(I) = IDF(I)-II
      DO 610 I = 1,KMAX
      II =            NDBE(I) *ALOG(UNIFM1(0.0)) - 0.5
      IF(II.EQ.0)II=- 1
  610 IDE(I) = IDE (I) - II
      IF (IND(3).EQ.0) GO TO 650
      WRITE (6,9610)(I,IDF(I),I = 1,IQMAX)
 9610  FORMAT(1,9H1PRINT OPTION THREE/39H FAILURE TYPE---DAY OF FIRST OCC
     1URRENCE/(1H 10(I3,1H-,I4,4X)))
      WRITE (6,9611)(I,IDE(I),I = 1,KMAX)
 9611  FORMAT(1H0/41H EMERGENCY TYPE---DAY OF FIRST OCCURRENCE/
     1 (1H 10(I3,1H-,I4,4X)))
C***BEGIN SIMULATION FOR EACH DAY---INITIALIZATIONS
  650  NIGNR=0
       NSUC1=0
       NSUC2=0
       NFALE=0
       NREPT=0
       DO 655 I=1,4
  655  NPRFM(I)=0
      DO 658  J=1,10
       DO 658 I=1,40
  658  CLSDTA(J,I)= 0.0
      USHT = 0.0
       HRSE=0.0
       HRSR=0.0
       HRSS=0.0
       MAXST=0.0
       MAXSTE=0
      DO 660 I = 1,IEMAX
  660 ZC(I) = 0.0
      DO 670 I = 1,IC
      TW(I) = 0.0
       TWP(I)=0.0
       TWS(I)=0.0
       MPCC(I)=0.0
      IDC(I) = 0.0
      DS(I) = 0.0
       NU(I)=0.0
  670 Z(I) = 0.0
      CML = 0.0
      CMLMX=-1.E10
       ICML=0
       SIDCMX=CMLMX
       IDCMX=0
      TEH = 0.0
       SFDIFF=0.0
       SEF=0.0
       ISIE=0
       APA=0.0
      DO 675 I=1,IQMAX
      CUT(I) = 0.0
      CDT (I) = 0.0
      CART(I) = 0.0
```

```
      EPL(I)=0.0
  675 CONTINUE
C
C     CALCULATE SEA STATE
C
      ICSS =9
      ATEM = UNIFM1 (0.0)
      DO 680 I=1,9
  705 FORMAT(1H0,2I5,2F7.4)
      IF (ATEM .GT. SESTA (I) ) GO TO 680
      ICSS = I - 1
      GO TO 685
  680 CONTINUE
  685 PSESIC = 0.0555 * ICSS
      DO 690 I=1,IC
      TPCOM (I) = PCOM (I)
      TSCOM (I) = SCOM (I)
      IF (UNIFM1(0.0)  .GE. PSESIC) GO TO  690
      TPCOM (I) = TPCOM (I) * (1- ICSS* 0,0555)
      TSCOM (I) = TSCOM (I) * (1- ICSS* 0,0555)
  690 CONTINUE
      WRITE (6,682) ICSS,PSESIC
  682 FORMAT(19H0CURRENT SEA STATE=I2/17H PERCENT SEASICK=F7.4)
      CALL DINPUT
      IF(ND .GE. IND(4))  WRITE(6,8502)
 8502 FORMAT(1H1)
C***IDENTIFY FAILURES AND EMERGENCIES FOR THE DAY
C***AND COMPUTE NEXT OCCURRENCE FOR EACH
  700 NR = 0
      KK = NOSE
      DO 710 I = 1,IQMAX
      IF (IDF(I).NE.ND) GO TO 710
      NR = NR+1
      KK = KK+1
      IEVENT(KK)=200+(I-1)*12  + 1
      II=RELH(I)*ALOG(UNIFM1(0.0))-.5
      IF(II.EQ.0)II=-1
      IDF(I) = IDF(I)-II
  710 CONTINUE
  750 NE = 0
      DO 760 I = 1,KMAX
      IF (IDE(I).NE.ND) GO TO 760
      NE = NE+1
      KK = KK+1
      IEVENT (KK) = I + 560
      II =          NDBE(I) * ALOG (UNIFM1(0.0)) - 0.5
      IF(II.EQ.0)II=- 1
      IDE (I) = IDE(I) - II
  760 CONTINUE
      NUMFAM = 0
      NOIFT = 0
      IST = (ICSS + 1) /10.
      DO 697 I=1,NOSE
      IF (NR + NOIFT .GE. 30) GO TO 697
      NOIF = 0
      IF (IFOI (I) .NE. 1) GO TO 697
```

```
      NUMFAM = NUMFAM + 1
      IF (NOIFT .GT. 10) GO TO 697
C
C     ACCESS TYPE DATA FROM DISC
      ITEM=IETYP(I)
      READ(12'ITEM,ERR=3000) ADURIO
C
      IF (NIQR .EQ. 0) GO TO 697
C
      DO 698 INIQ = 1,NIQR
      IF (NOIF .EQ. 1) GO TO 698
      RY2 = UNIFM1 (0.0)
      BTEM = 0.001
      IF(LODM.GT. 3) BTEM=0.01
      IF(LODM.GT.6) BTEM=0.03
      ATEM = FUNC(BTEM,RY2,IST)
      IF ( ATEM .LT. UNIFM1(0,0)) GO TO 698
      NOIF = 1
      KK = KK + 1
C
C     COUNTER
C
      NOIFT = NOIFT + 1
C
C     WHICH REPAIR SEQUENCE
C
      IEVENT(KK)=200+12*(IQR(NIQR)-1)+1
C
C     WHICH SCHEDULED EVENT HAS AN OIF
C
      IOIF (NOIFT) = I
  698 CONTINUE
  697 CONTINUE
C
C     NR IS NUMBER OF REPAIR FAMILIES
C
      NR = NR + NOIFT
      NOSE1 = 0
      NTE = NR + NE + NOSE
      DO 770 I =1, NOSE
      IF ( IFOI(I) .NE. 1) GO TO 770
      IEVENT (I) = I
      NOSE1 = NOSE1 + 1
  770 CONTINUE
C
C     RANDOMLY ASSIGNS REPAIRS THEN EMERGENCIES TO TASK SEQUENCE AND
C     THEN FILLS IN SCHEDULED EVENTS TO QUEUE IN ORDER OF INPUT
C
C***   GENERATE POINTERS FOR EVENTS FOR THIS DAY
  775 DO 780 I = 1,NTE
  780 PTR(I) = 0
      JJ = NOSE  + 1
      TEM1 = NTE-1
      DO 810 I = JJ,NTE
      II = UNIFM1(0.0)*TEM1+1.0
      IF(PTR(II)) 785,805,785
```

```
  785 KK = II
  790 II = II+1
      IF (II.GT.NTE) GO TO 795
      IF(PTR(II)) 790,805,790
  795 II = KK
  800 II = II-1
      IF (PTR(II).NE.0) GO TO 800
  805 KK = IEVENT(I)
      PTR(II) = KK
      INVS(KK) = II+1
  810 CONTINUE
      KK = 1
      DO 820 I=1,NOSE
      IF (IFOI(I) .NE. 1) GO TO 820
  815 IF(PTR(KK) .EQ. 0)  GO TO 818
      KK = KK+1
      GO TO 815
  818 PTR(KK) = I
  820 CONTINUE
C
C     KOUNT IS INCREMENT FOR NPTR TO INCLUDE OIF AND FAMILY MEMBERS
C
      IGAP = 0
      KOUNT = 0
      DO 831 I=1,NTE
      IPTR = PTR (I)
      IF (IPTR .NE. 0) GO TO 841
      IGAP = IGAP + 1
      GO TO 831
  841 CONTINUE
      NPTR (I + KOUNT - IGAP) = IPTR
      IF (IPTR .GE. 561) GO TO 831
C
C     ISW1 = 0 SCHEDULED AND REPAIR EVENTS
C     ISW1 = 1 REPAIR EVENTS FOR OIF
C
      ISW1 = 0
  835 IF (IPTR .GT. 200) GO TO 842
      INIF = NIF (IPTR) - 1
      IF (INIF .EQ. 0) GO TO 834
      GO TO 843
  842 INIF = IRE ((IPTR-200) /12 + 1) - 1
      IF (INIF .EQ. 0) GO TO 834
  843 DO 832 J=1,INIF
      KOUNT = KOUNT + 1
      NPTR (I + KOUNT - IGAP) = IPTR  + J
  832 CONTINUE
C
C     CHECK IF SECOND TIME THROUGH
C
  834 IF (ISW1 .EQ. 1) GO TO 831
      IF (NOIFT .EQ. 0) GO TO 831
      IF (IPTR .GT. 200) GO TO 831
      ISW1=1
      DO 833 J=1,NOIFT
      IF (IPTR .NE. IOIF(J) ) GO TO 833
```

```
C
C      HAVE AN OIF
C
       KOUNT = KOUNT + 1
       IPTR= IEVENT(NTE+J)
       GO TO 835
  833  CONTINUE
  831  CONTINUE
C
C      THIS LOOP COUNTS TOTAL NO. OF EVENTS
        DO 8 I=1,570
       IF(NPTR(I).EQ.0 ) GO TO 9
    8   CONTINUE
    9   NTE=I-1
C
       DO 821  I=1,NTE
       IF(NPTR(I).LE.200) GO TO 826
  821   CONTINUE
  826  KK=561
       NX(1,KK)=NPTR(I)
       PRB(1,KK)=1.1
       DO 824 I=1,NTE
       K=NPTR(I)
       INVS(K)=I +1
       IF(K.LE.200) GO TO 823
       IF(K.GT.560) GO TO 822
       IF (IRE((K-201) /12 + 1 ) .EQ. 1 .OR. IFOI(K) .EQ. 2) GO TO 822
       GO TO 824
  822   NX(1,K)=NX(1,KK)
        NX(2,K)=NX(2,KK)
        NX(3,K)=NX(3,KK)
       PRB(1,K)=PRB(1,KK)
       PRB(2,K)=PRB(2,KK)
       PRB(3,K)=PRB(3,KK)
       GO TO 824
  823   KK=K
  824   CONTINUE
  830  IEIE = 1
  840  IE = NPTR (IEIE)
       IFIRST = 1
C***    RESETS FOR EACH EVENT
  850  IPI = 0
       IG=0
       ITRY = 0
       IGNOR = 0
       DO 865 JI = 1 , NDS
       USH (JI) = 0.
  865  CONTINUE
C***    DETERMINE WHETHER EVENT SHOULD BE IGNORED
C
C       ACCESS TYPE DATA FROM DISC
C******     EMERGENCY IF TYPE= -1
       ITEM=IETYP(IE)
        IF(ITEM.EQ.(-1)) GO TO 851
       READ(12'ITEM,ERR=3000) ADURIO
       GO TO 854
```

```
851   ADUR=ART(IE-560)
      ASD=ASDE(IE-560)
      IESS=IESSE(IE-560)
      LODM=LODME(IE-560)
      KE=2
      INT=1
      NIQR=0
      IH=IHE(IE-560)
      ICLASS=5
      DO 852  I=1,10
       NREQ(I)=NREQE(I,IE-560)
      IRC(I)=IRCE(I,IE-560)
      IRC1(I)=IRCE1(I,IE-560)
852    IEC(I)=IECE(I,IE-560)
C
854   IF ( IE .GT. 200) GO TO 862
      IF (IESS .GE. IET) GO TO 855
      IGIND = 1
      GO TO 1815
855   KK = TS(IE)
       IGIND=4
      DO 860 I = 1,LMAX
      IF(KONC(I) .LT. KONT(I,KK))  GO TO 1815
860   CONTINUE
      IGIND=5
      KK=TS1(IE)
      DO 861 I=1,LMAX1
      IF(KONC1(I)   .LT.KONT1(I,KK)) GO TO 1815
861    CONTINUE
C
C     COMPUTE NUMBER OF HOURS PER SHIFT
C
862   SFTHRS = 24./FLOAT(NDS)
      IF ( IFIRST .EQ. 0) GO TO 857
      IFIRST = 0
       IF (NPTR (1) .EQ. IE) GO TO 863
857   IF (NIF(IE) .GT. 1) GO TO 863
      IF (IFOI (IE) .GT. 1) GO TO 863
      IF ( IG .GT. 1) GO TO 863
C
C     HAVE FIRST EVENT IN ONE EVENT FAMILY WITH ONE MAN GROUP
C
      JJ=MAT(1)
      LL = ITYPE (JJ)
      IF (NREQT(LL) .NE. 1) GO TO 863
      ATEM = KTEMP * SFTHRS
      IF(ADUR+Z(JJ).LE.ATEM+0.33)GO TO 1150
863    CONTINUE
      JJ = IPE(IE)
      JNDS = NDS
C
C     DETERMINE EARLIEST SHIFT JOB CAN BE STARTED ON AND LATEST TIME BY
C    1 JOB MUST BE COMPLETED
C
      III = (AMAX1(ZC(JJ),ST(IE)))/SFTHRS + 1.0
      IF(KE    .EQ.1)JNDS=TL(IE)/SFTHRS+ .99
```

```
C     LSHIFT = 0--FIRST SORT THROUGH ALL POSSIBLE SHIFTS
C     LSHIFT = 1-- SECOND SORT WITH DESIRED SHIFT
C
      LSHIFT = 0
  905 FORMAT (10H0SHIFTHRS=F11.3,3I6)
      GO TO 877
C
C     BRANCH TO HERE WHEN LSHIFT = 1
C
  878 III = KTEMP
      JNDS = KTEMP
  877 DO 875 JI = III,JNDS
C***   IG  IS TOTAL NUMBER OF MEN REQUIRED FOR EVENT
      WRITE(6,1066) KTEMP,III,JNDS
 1066 FORMAT(1H04I10)
      IG = 0
      IPI =0
      IGNOR =0
      DO 880 I = 1,NTMAX
  880  NREQT(I)=NREQ(I)
C***   SELECTION OF PERSONNEL FOR EACH TYPE
C***   KIND = 0  WHEN SELECTING PRIMARY SPECIALTIES
C***   KIND = 1  WHEN SELECTING SECONDARY SPECIALTIES
       DO 885 I=1,IC
  885 MCHSN(I)=0
      KIND = 0
      II = 1
      KA = 0
      IF (INT     .EQ.2) GO TO 1020
  900 IF (NREQT(II).NE.0) GO TO 925
  910 IF (II.EQ.NTMAX) GO TO 920
      II = II+1
      KA = 0
      GO TO 900
  920 IF (IPI.EQ.0) GO TO 1060
       IF(KIND) 1060,1020,1060
  925 IF (KA.NE.0) GO TO 990
       TEM1=TL(IE)
      LL = KIND*20
      DO 950 I = 1,IC
      LL = LL+1
       IF(MCHSN(I).NE.0) GO TO 950
C
C     TRIVIAL CASE IS IDS(JI ,1) = 1 FOR ALL JI
C     THIS CASE IS ORIGINAL --NO SHIFT--MODEL
C
      IF (IE .GT. 200) GO TO 930
       IF (IDS(JI,I) .NE.  1) GO TO 950
      NKOUNT = NKOUNT + 1
      IF (NKOUNT .GT. 100) GO TO 934
      WRITE (6,941) I,JI,SFTHRS
  934 CONTINUE
      ZTEMP = JI * SFTHRS + 1.0
      IF (ZTEMP .GT. 24.0) ZTEMP = 24.0
      IF (NKOUNT .GT. 100) GO TO 942
      WRITE (6,941) JI,I,SFTHRS,ZTEMP,Z(I)
```

```
  941 FORMAT (6HOZTEMP 2I5,5F10.3)
  942 CONTINUE
      IF (Z(I ) .GT. ZTEMP) GO TO 950
  930 CONTINUE
      IF (IPSS(LL).NE.II) GO TO 950
       IF(Z(I).GT.TEM1) GO TO 950
      IF (TW(I).GT.WORK2) GO TO 950
      KA = KA+1
      MAVAIL(KA) = I
       CALR=PWR(I)
      TEM2 = IEC(II)
      IF (CALR.LE.TEM2) GO TO 935
      CALR = 1.0
      GO TO 940
  935 CALR = CALR/TEM2
  940 TAVAIL(KA) = 1000.0-10.0*TW(I)+CALR*TPSCOM (LL)
  950 CONTINUE
      IF (KA.NE.0) GO TO 960
  955 IPI = 1
      IF (KIND.EQ.0) GO TO 910
  958 IF (LSHIFT .EQ. 1) GO TO 910
      USH(JI) = USH (JI) +ADUR     *FLOAT(NREQT(II))
      GO TO 910
  960 KK = KA-1
      IF (KK.EQ.0) GO TO 990
      DO 980 I = 1,KK
      LL = KA-I
      DO 970 J = 1,LL
      TEM1 = TAVAIL(J)
      IF (TEM1.LE.TAVAIL(J+1)) GO TO 970
      TAVAIL(J) = TAVAIL(J+1)
      TAVAIL(J+1) = TEM1
      NN = MAVAIL(J)
      MAVAIL(J) = MAVAIL(J+1)
      MAVAIL(J+1) = NN
  970 CONTINUE
  980 CONTINUE
  990 IF (KA.EQ.0) GO TO 955
      NN = MAVAIL(KA)
      KA = KA-1
       IF((IE.GE.561).OR.(JBSS     .EQ.100)) GO TO 1000
      IF (TW(NN)+ADUR     .LE.WORK1) GO TO 1000
  995  IF(KIND.EQ.1) GO TO 958
      IPI = 1
      GO TO 910
 1000  IF(TW(NN).GT.WORK2) GO TO 995
       IG=IG+1
       MCHSN(NN)=1
      MA(IG,II) = NN
      MAT(IG) = NN
      ITYPE(NN) = II
      NREQT(II) = NREQT(II)-1
      IF(KA .NE. 0)  GO TO 900
      IF(NREQT(II)) 955,910,955
C
C     RESET FOR SECONDARY SEARCH
```

```
C
 1020 KIND = 1
      II = 1
      GO TO 900
C***   SELECT LEADER
 1060 CONTINUE
  875 CONTINUE
      WRITE(6,1063) (USH(IABC),IABC=III,JNDS)
 1063 FORMAT(9HOUSHOURS=12F10.5)
C
C     LSHIFT = 0     CHECK ALL SHIFTS
C     LSHIFT = 1     ONCE THROUGH LOOP WITH BEST SHIFT
C
      IF (LSHIFT .EQ. 1) GO TO 1064
C
C     ASSIGN JOB TO SHIFT (FIRST WITH ZERO USH OR MINIMUM USH)
C
      KTEMP = III
      IF ( III .EQ. JNDS) GO TO 1064
      IIIP1 = III + 1
      DO 1061 JI = IIIP1,JNDS
      RTEMP = USH(JI) - USH(KTEMP)
      WRITE (6,1072) JI,USH(JI), USH(KTEMP) ,RTEMP
 1072 FORMAT(1H0I6,3F9.5)
      IF (RTEMP) 1076,1061,1061
 1076 RTEMP = RTEMP + 0.0001
      IF (RTEMP) 1078,1061,1061
 1078 CONTINUE
      KTEMP = JI
 1061 CONTINUE
      LSHIFT = 1
      GO TO 878
 1064 FLIG = IG
      IF(IG .NE. 0)  GO TO 1065
      IGIND = 2
C      DO 1062 I=1,NTMAX
C1062   IG=IG+NREQT(I)
C      USH=USH+ADUR(IE)*FLOAT(IG)
      GO TO 1815
 1065 LI = MAT(1)
      JJ = ICE(LI)
      IF (IG.EQ.1) GO TO 1150
      DO 1080 I = 2,IG
      KK = MAT(I)
       IF(ICE(KK)-JJ) 1075,1070,1080
 1070 IF (TPCOM(KK) .LE. TPCOM(LI)) GO TO 1080
 1075 LI = KK
      JJ = ICE(KK)
 1080 CONTINUE
C
C     DETERMINE Z1 = EARLIEST TIME ALL GROUP IS AVAILABLE
C
 1150 KK = 0
      Z1 = 0.0
      DO 1160 I = 1,IG
      JJ = MAT(I)
```

```
 1160 Z1 = AMAX1(Z1,Z(JJ))
C*****   DETERMINE EARLIEST TIME WHEN THE EVENT CAN BEGIN
      JJ = IPE(IE)
      TEM2=0.0
      IF(JJ.NE.0) TEM2=ZC(JJ)
      ATEM = KTEMP *SFTHRS
      Z2=AMAX1(Z1,TEM2,ST(IE),ATEM)
      IF(Z2 .LT. TL(IE))  GO TO 1162
      IGIND = 3
      USH(KTEMP) = USH (KTEMP) + ADUR     * FLIG
      GO TO 1815
C
 1162 DO 1165 I = 1,IG
      JJ = MAT(I)
C*****   IS A NON-SCHEDULED REST OR SLEEP REQUIRED DUE TO START TIME
      WH(JJ) = Z2-Z(JJ)
      IF (WH(JJ).NE.0.0) KK = 1
 1165 CONTINUE
       IF(KK.EQ.0) GO TO 1280
       TEM2=CN+.5
C*****   IS THE TIME SINCE LAST EVENT LONG ENOUGH TO ALLOW SLEEP
      DO 1260 I=1,IG
      JJ = MAT(I)
       IF(WH(JJ).LT.TEM2) GO TO 1240
C***     IS SLEEP QUOTA FOR DAY USED
      IF(DS(JJ) .GE. MAXSL)  GO TO 1240
C***     OR  **  IS FATIGUE UNDER THRESHOLD
      IF(FAT(JJ) .LE. TFAT)  GO TO 1240
C***     NEITHER  **  SUM SLEEP THIS DAY FOR EACH M IN G
       TEM1=MAXSL-DS(JJ)
C***     LIMIT WH(JJ)  SO THAT DS .LE. MAXSL
       DS(JJ)=AMIN1(DS(JJ)+WH(JJ)-.5,MAXSL)
C***     CALCULATE TIME FATIGUE DUE TO SLEEP RELIEF FOR EACH M IN G
       TEM1=AMIN1(WH(JJ),TEM1)-.5
      IF(TEM1 .LE. 9.0)  GO TO 1205
 1200 FAT(JJ) = 0.0
      GO TO 1220
 1205 IF(TEM1 .LT. 1.0)  GO TO 1210
      FAT(JJ) = FAT(JJ)*((138.0-19.0*TEM1)/140.0+0.2*UNIFM1(0.0))
      GO TO 1220
 1210 FAT(JJ) = FAT(JJ)*(0.9-0.05*TEM1+0.2*UNIFM1(0.0))
 1220 IF(FAT(JJ) .LT. 0.0)  FAT(JJ) = 0.0
      IF(FAT(JJ) .GT. 1.0)  FAT(JJ) = 1.0
      ACAL(JJ) = 0.0
      TEM1 = FAT(JJ)
      IF(TEM1 .GT. 0.9)  GO TO 1225
      IF(TEM1 .GT. 0.15)  GO TO 1224
      HSLS(JJ) = 53.333333 * FAT(JJ)
      GO TO 1260
 1224 HSLS(JJ) = 14.666667*TEM1+5.8
      GO TO 1260
 1225  HSLS(JJ)=AMAX1(310.0*TEM1-260.0,0.0)
      GO TO 1260
C***     ADJUST HOURS SINCE LAST SLEEP FOR THIS M
 1240 HSLS(JJ) = HSLS(JJ) + WH(JJ)
C        CALCULATE FATIGUE BUILDUP FOR THIS MAN DUE TO REST
```

```
      FAT(JJ) = FBUILD(HSLS(JJ))
 1260 CONTINUE
C***   CALCULATE PHYSICAL CAPABILITY OF EACH MAN IN GROUP
C***  SAVE MAX PHYS CAPABILITY FOR EACH MAN
 1280 GPCC = 0.0
      DO 1295 I = 1,IG
      JJ = MAT(I)
      KK = IPS(JJ)
       TEM2=IEC(KK)   /PWR(JJ)
      IF (TEM2.GE.1.0) GO TO 1285
      EXER = 1.0
      GO TO 1290
 1285 EXER = (ZPC-TEM2)/(ZPC-1.0)
 1290 TEM1=(ACAL(JJ)/CAL(JJ))**2
      TEM1 = PC(JJ)*PI(JJ)*(1.0-(1.0-K1)*TEM1)*EXER*(1.0-0.1*FAT(JJ))
      IF (TEM1.LT.0.0) TEM1    = 0.0
      IF (TEM1.GT.2.0) TEM1    = 2.0
       MPCC(JJ)=AMAX1(MPCC(JJ),TEM1)
       PCC(JJ)=TEM1
 1295 GPCC = GPCC+TEM1
      GPCC = GPCC/FLIG
C***    CALCULATE GROUP STRESS THRESHOLD AND GROUP STRESS
      GSTRM=0.0
      DO 1370 I = 1,IG
      JJ = MAT(I)
 1370 GSTRM = GSTRM+STRM(JJ)
      GSTRM = GSTRM/FLIG
 1375  IF(IE.GE.560) GO TO 1377
      GSTR = (ADUR    *(.875*LODM    *.025))/(TL(IE)-Z2)
       GO TO 1378
 1377  GSTR=GSTRM
1378  IF (GSTR.GT.5.0) GSTR = 5.0
       IF(GSTR.LT.1.0) GSTR=1.0
C***    CALCULATIONS FOR PERFORMANCE TIME AND END TIME
 1300 IF(ASD    .NE.0.0) GO TO 1380
      IF (KE    .NE.1) GO TO 1310
      IF((Z2+ADUR    ) .GT. TL(IE))  GO TO 1320
      PT(IE) = ADUR
      ZC(IE) = TL(IE)
      GO TO 1550
 1310 PT(IE) = ADUR
      ZC(IE) = Z2+PT(IE)
      GO TO 1550
 1320 PT(IE) = TL(IE)-Z2
      ZC(IE) = TL(IE)
      GO TO 1550
 1380 PAF = 1.0
C***    CALCULATE GROUP PERFORMANCE, GROUP ASPIRATION LEVEL
      GPERF = 0.0
      GASP = 0.0
      DO 1390 I = 1,IG
      JJ = MAT(I)
      GPERF = GPERF+PERF(JJ)
 1390 GASP = GASP+CASP(JJ)
      GPERF = GPERF/FLIG
      GASP = GASP/FLIG
```

```
C***   SELECT ONE OF FIVE CASES  COMPARING GASP WITH GPERF
C***            AND  GSTR WITH GSTRM
      TEM1 = GASP-GPERF
      IF (ABS(TEM1).LE.0.02) GO TO 1460
      TEM2 = GSTR-GSTRM
      IF (TEM1.GT.0.0) GO TO 1395
      IF (TEM2) 1410,1450,1450
 1395 IF (TEM2) 1400,1430,1430
 1400 PAF = 1.0-0.4*TEM1
      GO TO 1460
 1410 DO 1420 I = 1,IG
      JJ = MAT(I)
       TEM3=PERF(JJ)-CASP(JJ)
       IF(TEM3.LE.0.0) GO TO 1420
       TEM3=CASP(JJ)+0.1*TEM3*DNORM1(0,0)
      IF (TEM3.GT.1.0) TEM3 = 1.0
       CASP(JJ)=TEM3
 1420  CONTINUE
      GO TO 1460
 1430 DO 1440 I = 1,IG
      JJ = MAT(I)
 1440 CASP(JJ) = PERF(JJ)
      PAF = 1.0+0.4*TEM1
      GO TO 1460
 1450 GSTR = 0.9*GSTRM
C***    CALCULATE PERFORMANCE TIME
 1460 IF (GPCC.GE.1.0) GO TO 1470
      SF = 2.0-GPCC
      GO TO 1480
 1470 SF = 1.5-GPCC*0.5
 1480 TEM3 = 0.0
      DO 1490 I = 1,IG
      JJ = MAT(I)
 1490 TEM3 = TEM3+PACE(JJ)
      GPACE = TEM3/FLIG*SF*PAF
C
C     TEST FOR REPAIRS
C
      IF (IE .LT. 201) GO TO 1492
      IF ( IE .GT. 560) GO TO 1492
      TEM1 = 1 + (ASD *ASD)/(ADUR * ADUR)
      V = EXP(ALOG(ADUR/SQRT(TEM1)) + DNORM1(0,0) * SQRT (ALOG(TEM1)))
      GO TO 1493
 1492  V= ADUR + DNORM1(0,0) * ASD
 1493 CONTINUE
      ADUR 2 = ADUR/2.
      V = AMAX1(ADUR2,V)
C
      IF (TEM2.GE.0.0) GO TO 1500
      TEM3 = (GSTR-1.0)/(GSTRM-1.0)
      PT(IE) = GPACE + V *((-  2.3075 * TEM3) + (3.4722 * TEM3 * TEM3)
     1 + (-1.829 * TEM3 * TEM3 * TEM3)+1)
C     PT(IE) = GPACE*V*(1.0+TEM3*(-2.55075+TEM3*(3.4722-1.829*TEM3)))
      GO TO 1535
 1500 IF (TEM2.GT.1.0) GO TO 1510
      PT(IE)=GPACE*((2.0*TEM2+1.0)*V-TEM2*ADUR)
```

```
      GO TO 1535
 1510 PT(IE) = (3.0*V-ADUR     )*GPACE
C        LIMIT PT(IE)
 1535 IF(PT(IE) .GE. 0.0)  GO TO 1537
      PT(IE) = 0.0
      GO TO 1539
 1537 TEM1 = 4.0*ADUR
      IF(PT(IE) .LE. TEM1)  GO TO 1539
      PT(IE) = TEM1
C***    CALCULATE REAL TIME OF EVENT COMPLETION
 1539 ZC(IE) = Z2 + PT(IE)
      IF(ZC(IE).LE.TL(IE)) GO TO 1545
      PT(IE)=TL(IE)-Z2
      USH(KTEMP) = USH(KTEMP) + FLIG *(ZC(IE)  - TL(IE) )
      ZC(IE)=TL(IE)
 1545 IF(ZC(IE).LE.24.0) GO TO 1550
      PT(IE) = 24.0-Z2
      ZC(IE) = 24.0
 1550 CONTINUE
C***    UPDATE HSLS, TW,Z,CBAL,ACAL,IDC FOR EACH MAN
 1560 ITRY = ITRY+1
      IF(IE.GT.560) GO TO 1566
      DO 1565 I=1,NIOR
      ITEM=IOR(I)
      IF(IE.GE.201) GO TO 1562
      CUT(ITEM)=CUT(ITEM)+PT(IE)
      GO TO 1565
 1562 CDT(ITEM)=CDT(ITEM)+PT(IE)
      CART (ITEM) = CART (ITEM) + ADUR
 1565  EPL(ITEM)=CUT(ITEM)/(CUT(ITEM)+CDT(ITEM))
 1566  CONTINUE
      TEM1 = PT(IE)
      TEM2 = ZC(IE)
      TEM3=TEM1
       SIDC=0.0
      DO 1580 I = 1,IG
      JJ = MAT(I)
      HSLS(JJ) = HSLS(JJ)+TEM1
      Z(JJ) = ZC(IE)
      KK = ITYPE(JJ)
      CCAL(JJ) = IEC(KK)    *TEM3*(.95+UNIFM1(0.0)/10.)
      ACAL(JJ) = ACAL(JJ)+CCAL(JJ)
      IDC(JJ) = IDC(JJ)+CCAL(JJ)
      TW(JJ) = TW(JJ)+TEM1
       IF(KK.EQ.IPS(JJ)) GO TO 1579
       CLSDTA(7,ICLASS)= CLSDTA(7,ICLASS) + PT(IE)
       TWS(JJ)=TWS(JJ)+PT(IE)
       GO TO 1580
 1579 TWP(JJ)=TWP(JJ)+PT(IE)
       CLSDTA(6,ICLASS)= CLSDTA(6,ICLASS) + PT(IE)
 1580 SIDC = SIDC + CCAL(JJ)
       IF(SIDC.LE.SIDCMX) GO TO 1582
       SIDCMX=SIDC
       IDCMX=IE
 1582 TEM2=LODM     *TEM1
C***    ACCUMULATE CML AND SAVE MAX
```

```
      IF(CMLMX.GE.TEM2) GO TO 1585
      CMLMX=TEM2
      ICML=IE
 1585 CML=CML+TEM2
C***    EVENT HAZARD AND SUM FOR DAY (TEH)
      EH = TEM1*IH
      TEH = TEH+EH
C***    CALCULATE PERFORMANCE ADEQUACY
 1600  IF(ITRY.GT.1) GO TO 1645
      IF (GSTRM.GE.GSTR) GO TO 1610
      IF (GSTR.LE.5.0) GO TO 1620
      ES = 0.0
      GO TO 1630
 1610 ES = (1.0-BE)/(GSTRM-1.0)*GSTR+BE
      GO TO 1630
 1620 ES = (5.0-GSTR)/(5.0-GSTRM)
 1630 TEM1 =TPCOM(LI)
      IF (ITYPE(LI).NE.IPS(LI)) TEM1 =TSCOM(LI)
      EC = 2.0*TEM1
      EA = 2.0*CASP(LI)
      DO 1640 I = 1,IG
      JJ = MAT(I)
      IF (ITYPE(JJ).NE.IPS(JJ)) TEM2 =TSCOM(JJ)
      TEM2 =TPCOM(JJ)
      EC = EC+TEM2
 1640 EA = EA+CASP(JJ)
      TEM2 = FLIG+2.0
      EC = EC/TEM2
      EA = EA/TEM2
       EF=AMIN1(1.0,GPCC)
       GO TO 1647
 1645  EC=AMIN1(EC+.2,1.0)
 1647 TEM1 = EF+EA
      WRITE (6,1650) PA,TEM1,ES,EF,EA,EC
      PA = SQRT((3.0*EC*(TEM1+ES)+ES*TEM1+EF*EA)/12.0)
      WRITE (6,1650) PA,TEM1,ES,EF,EA,EC
       APA=APA+PA
C***   COMPUTE EFFICIENCY FACTOR
C
      SEF = SEF + (PA*FLOAT(IESS     ))/(CASP(LI)*K7)
      WRITE (6,1650) PA,CASP(LI),K7 ,SEF
 1650 FORMAT(5H SEF 6F10.5)
      WRITE (6,1655) IESS
 1655 FORMAT (5H IESS 5I10)
       ISIE=ISIE+IESS
C***    CALCULATE TIME FATIGUE AND PHYS CAP FOR ALL MEN IN GROUP
 1700 GPCC=0.0
      DO 1740 I = 1,IG
      JJ = MAT(I)
      FAT(JJ) = FBUILD(HSLS(JJ))
      KK = ITYPE(JJ)
       TEM2=IEC(KK)    /PWR(JJ)
      IF (TEM2.GE.1.0) GO TO 1725
      EXER = 1.0
      GO TO 1730
 1725 EXER = (ZPC-TEM2)/(ZPC-1.0)
```

```
1730 TEM1=(ACAL(JJ)/CAL(JJ))**2
     TEM1 = PC(JJ)*PI(JJ)*(1.0-(1.0-K1)*TEM1)*EXER*(1.0-C.1*FAT(JJ))
     IF (TEM1.GT.2.0) TEM1 = 2.0
     IF (TEM1.LT.0.0) TEM1 = 0.0
      MPCC(JJ)=AMAX1(MPCC(JJ),TEM1)
     PCC(JJ) = TEM1
1740 GPCC = GPCC+TEM1
     GPCC = GPCC/FLIG
C***    CALCULATE NEW CONSUMABLE LEVELS
     TEM1 = PT(IE)
     DO 1750 I = 1,LMAX
      KONE(I)=IRC(I    )*TEM1
     KONC(I) = KONC(I)-KONE(I)
1750 CONTINUE
     DO 1752 I=1,LMAX1
     KONE1(I)=IRC1(I)
     KONC1(I)=KONC1(I)-KONE1(I)
1752  CONTINUE
C***    NO CONSUMABLES USED UP
C***      DETERMINE SUCCESS OR FAILURE FOR EVENT
1755 SUCC = YU
      FDIFF=CASP(LI)*K7-PA
      IF(FDIFF.LT.0.0) SUCC=ESSS
      CLSDTA(1,ICLASS)= CLSDTA(1,ICLASS) + 1
      CLSDTA(8,ICLASS)= CLSDTA(8,ICLASS) + PA
      CLSDTA(9,ICLASS)= CLSDTA(9,ICLASS) + FDIFF
     IF (SUCC.EQ.ESSS) GO TO 1770
      SFDIFF=SFDIFF+FDIFF
C***    FAILED
     DO 1760 I = 1,IG
     JJ = MAT(I)
1760 NOFAIL(JJ) = NOFAIL(JJ)+1.0
      NFALE=NFALE+1
      CLSDTA(4,ICLASS)= CLSDTA(4,ICLASS) + 1
     GO TO 1790
C***    SUCCESS
1770 DO 1780 I = 1,IG
     JJ = MAT(I)
      NU(JJ)=NU(JJ)+1.0
1780 NOSUC(JJ)=NOSUC(JJ)+1.0
     KK = 1
      IF(ITRY.EQ.1) GO TO 1775
      NSUC2=NSUC2+1
      CLSDTA(3,ICLASS)= CLSDTA(3,ICLASS) + 1
       GO TO 1790
1775 NSUC1=NSUC1+1
      CLSDTA(2,ICLASS)= CLSDTA(2,ICLASS) + 1
C***    CALCULATE PERFORMANCE LEVEL FOR MEN IN GROUP
1790 DO 1800 I = 1,IG
     JJ = MAT(I)
     TEM1 = NOSUC(JJ) + NOFAIL(JJ)
     IF(TEM1 ,GT. 5.0  .AND.  NOSUC(JJ) ,GT. 0.0)
    X   PERF(JJ) = NOSUC(JJ)/TEM1
1800 CONTINUE
      NPRFM(1)=NPRFM(1)+1
     USHT = USHT + USH(KTEMP)
```

```
C***    UPDATE MAX STRM FOR TJE DAY
        IF(MAXST.GE.GSTR) GO TO 1805
        MAXST=GSTR
        MAXSTE=IE
 1805 GO TO 1820
C***    COME HERE FOR IGNORE LOGIC
 1815 IGNOR = 1
        NIGNR=NIGNR+1
       PT(IE) = 0.0
        CLSDTA(1,ICLASS)= CLSDTA(1,ICLASS) + 1
        CLSDTA(5,ICLASS)= CLSDTA(5,ICLASS) + 1
       GO TO 1824
C***    TEST FOR PRINT OPTION AFTER UPDATING HOURS SPENT IN ACTIVITIES
 1820  IF(IE.GT.200) GO TO 1821
        HRSS=PT(IE)*FLIG+HRSS
        NPRFM(2)=NPRFM(2)+1
        GO TO 1824
 1821  IF(IE.GT.560) GO TO 1822
        HRSR=PT(IE)*FLIG+HRSR
        NPRFM(3)=NPRFM(3)+1
        GO TO 1824
 1822 HRSE=HRSE+PT(IE)*FLIG
        NPRFM(4)=NPRFM(4)+1
 1824 IF(ND-IND(4)) 1890,1825,1830
 1825 IF  (IE.LT.IND(5)) GO TO 1890
 1830 IF(IE .GT. 560)  GO TO 1850
      IF(IE .GT. 200) GO TO 1840
      KK = 1
      LL = IE
      IF(IGNOR .EQ. 1)  GO TO 1880
      GO TO 1860
 1840 KK = 4
      LL=(IE - 201)/12+1
      IF(IGNOR .EQ. 1)  GO TO 1880
      GO TO 1860
 1850 KK = 7
      LL=IE-560
      IF(IGNOR .EQ. 1)  GO TO 1880
C***    PRINT EVENT DATA
 1860 II = KK+2
      IPET = IPE(IE)
      TEM1 = 0.0
      IF (IPET.NE.0) TEM1 = ZC(IPET)
      WRITE(6,9860) (TITLE(I),I=KK,II),LL,ND,ITER,SUCC,Z1,ST(IE),IPET,
     1 TEM1,Z2,PT(IE),ZC(IE),USH(KTEMP),GSTR,GPCC,GPACE,GASP,PA,EH,
     2 (KONE(I),I=1,10),(KONC(I),I=1,10), (KONE1(I),I=1,10),(KONC1(I),I=
     2 1,10)
 9860 FORMAT(/1H03A6,I3,5H  DAY,I3,11H  ITERATION,I3,2X,1A6/
     1 10H MEN AVAIL ,F5.1,15H  START ALLOWED,F5.1,13H  PRIOR EVENT,
     2 I3,9H FINISHED,F6.2,13H EVENT STARTS,F6.2,6H LASTS,F6.2,
     3 5H ENDS,F6.2,13H UNMANNED HRS,F7,2/
     4 13H GROUP STRESS,F5.2,9H PHYS CAP,F5.2,5H PACE,F4.1,5H  ASP,F5.2,
     5 8H PERF AD,F6.2,4H WAZ,F5.1,/1X,17HPER HR CONS USED=10F6.0,
     9 /1X,17HPER HR CONS LEFT=10F6.0,/1X,15HUNIT CONS USED=10I6,
     9 /1X,15HUNIT CONS LEFT=10I6,/
     6 111HOMAN TYPE  SPEC   LDR RANK FATIGUE PHYS CAP HRS WRKD CALORIE
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```
     7 CALS+HRS SINCE SLEEP IDLE HRS SLEPT CUM PERF  ASP)
      DO 1870 I = 1,IG
      II = MAT(I)
      KK = ITYPE(II)
      TEM1 = PEA
       IF(KK.NE.IPS(II)) TEM1=ESSS
      TEM2 = BLANK
      IF (II.EQ.LI) TEM2 = STAR
      TEM3=IEC(KK)
      WRITE(6,9865) II,KK,TEM1,TEM2,ICE(II),FAT(II),PCC(II),TW(II),
     1 CCAL(II),ACAL(II),HSLS(II),WH(II),DS(II),PERF(II),CASP(II)
 9865 FORMAT (I4,I5,2A6,I5,F8.3,F9.3,F9.2,F9.1,F10.1,F11.1,F5.1,F10.1,
     1 F9.2,F5.2)
C
 1870 CONTINUE
      GO TO 1890
C***    PRINT IGNORE DATA
 1880 II = KK+2
      WRITE(6,9880) (TITLE(I),I=KK,II),LL,ND,ITER
 9880 FORMAT(/1H03A6,I3,5H  DAY,I3,11H  ITERATION,I3,
     1 18H IS IGNORED DUE TO)
      IF(IGIND .GT. 1)  GO TO 1881
      WRITE(6,9881) IESS
 9881 FORMAT(1H+,63X,20HLOW ESSENTIALITY OF I2)
      GO TO 1890
 1881 IF(IGIND .GT. 2)  GO TO 1882
      WRITE(6,9882)
 9882 FORMAT(1H+,63X,10HNULL GROUP)
      GO TO 1890
 1882 IF(IGIND .GT. 3)  GO TO 1883
      WRITE(6,9883)
 9883 FORMAT(1H+,63X,17HNO TIME AVAILABLE)
      GO TO 1890
 1883 IF (IGIND .GT. 4) GO TO 1884
      KK = TS (IE)
      WRITE(6,9884) (KONT(I,KK),I=1,10)
 9884 FORMAT(1H+,63X,38HCONSUMABLE (UNIT/HOUR) BELOW THRESHOLD/1H0,10F8
     1 0)
      GO TO 1890
 1884 KK = TS1 (IE)
      WRITE (6,9885) (KONT1(I,KK),I=1,10)
 9885 FORMAT(1H+,63X,34HCONSUMABLE (UNITS) BELOW THRESHOLD/1H0,10F8.0)
C***    CHECK IF RETRY OF EVENT IS NECESSARY
 1890 IF(SUCC.EQ.ESSS) GO TO 1892
       IF(ITRY.GT.1) GO TO 1892
      IF(IGNOR .EQ. 1)  GO TO 1892
       IF(RTU(IE).EQ.3) GO TO 1892
      Z1=ZC(IE)
      Z2=Z1
       NREPT=NREPT+1
       IF(RTU(IE).EQ.1) GO TO 1539
 1810 PT(IE)=0.5*PT(IE)+ASD    *DNORM1(0.0)
      GO TO 1539
C***    INCREMENT EVENT COUNTER AND TEST FOR END OF DAY
 1892 IEIE = INVS(IE)
      KK = NPTR(IEIE)
```

```
      IF(NPTR(IEIE) .EQ. 0)  GO TO 1920
      IF( NPTR(IEIE) .LE. 200)  GO TO 1900
C     KK = IE
      IE = NPTR(IEIE)
C***    IF EVENT IS NOT SCHEDULED WE MUST PRESERVE CHOICE OF FOLLOWING
C***        EVENT FROM NX AND PRB FOR CURRENT EVENT
C     DO 1895 I = 1,3
C     NX(I,IE) = NX(I,KK)
C1895 PRB(I,IE) = PRB(I,KK)
      GO TO 850
C***    DETERMINE NEXT EVENT USING NX AND PRB
 1900 TEM1 = UNIFM1(0.0)
      KK = 1
      IF (TEM1.LT.PRB(1,IE)) GO TO 1910
      KK = 2
      IF (TEM1.LT.PRB(1,IE)+PRB(2,IE)) GO TO 1910
      KK = 3
 1910 IE = NX(KK,IE)
      GO TO 850
C***    CALCULATE AVE PHYS WORKLOAD AND COMPETANCE FOR EACH CREW MEMBER
 1920 CCC = 0.0
      ETEM = 0.0
      TEMP = IC
      DO 1930 I = 1,IC
      APW(I) = IDC(I)/CAL(I)*TW(I)/WORK1
      IF (TW(I) .GT. 0.001) GO TO 1921
      TEMP = TEMP - 1.0
      GO TO 1922
 1921 ETEM = ETEM + PERF(I)
 1922 IF (PCOM(I).GE.CASP(I)) GO TO 1930
       PCOM(I)=(CASP(I)-PCOM(I))*NU(I)*0.0017+PCOM(I)
 1930 CCC = CCC+PCOM(I)
      CCC = CCC/FLIC
      ETEM = ETEM/TEMP
C***   PERFORMANCE EFFICIENCY
       TEM1=(1.0-(USHT/(WORK1*FLIC)))*(SEF/FLOAT(ISIE))
      WRITE (6,1066) NIGNR,NSUC1,NSUC2,NFALE
      WRITE (6,1063) TEM1
       PEFF=TEM1*(1.0-(FLOAT(NIGNR)/FLOAT(NSUC1+NSUC2+NFALE)))
C
C     COMPUTE EQUIP AND HUMAN STATS  FOR HURT
      ATEM=0.
      BTEM=0.
      CTEM=0.
      DTEM=0.
      TEM1=IQMAX
      DO 1932  I=1,IQMAX
      IF (CDT (I) + CUT(I) .GT. 0.001) GO TO 1931
      TEM1 = TEM1 - 1.0
      GO TO 1932
 1931 CONTINUE
      ATEM=ATEM+ EPL(I)
      BTEM=BTEM + CART(I)
      CTEM=CTEM+ CDT(I)
      DTEM=DTEM+ CUT(I)
 1932  CONTINUE
```

```
      AEPL=ATEM/TEM1
      EPEFF=AEPL/CTEM*BTEM
      IF(EPEFF.LT.0.) EPEFF=0.
      IF(EPEFF.GT.1.) EPEFF=1.
      EMTBF=DTEM/(DTEM+CTEM)
      EMTTR=BTEM/FLOAT(NR)
      SRL=0.7+8.571*(ETEM-0.65)*(AEPL-0.9)
      SPL=0.7+8.571*(PEFF-0.65)*(EPEFF-0.9)
      SGEM=((SRL-0.7)**2+(SPL-0.7)**2)/2.0
      IF(SGEM.LT.0.) SGEM=0.
      SGEM=SQRT(SGEM)
C
       IF(ND.EQ.NDMAX) GO TO 1960
C***    CALCULATE PHYS INCAPACITIES
      NPI = IPUYSN(FLIC/MPI)
      IF (NPI.EQ.0) GO TO 1960
      DO 1950 I = 1,NPI
      II = UNIFM1(0.0)*FLIC
      PI(II) = 0.2*UNIFM1(0,0)+0.75
      KK = IPUYSN(PID)
       IF(KK.EQ.0) PI(II)=1.0
      IF (KK.GE.1) KK = KK-1
 1950 PI2(II) = KK
C***    CALCULATE SAFETY INDEX
 1960  CONTINUE
       THW=0.0
       DO 1970 I=1,IC
 1970 THW=THW+TW(I)
      HR = TEH/(9.*THW)
      CML = CML/(9.*THW)
      SI = 9./8.*(1.-HR)
 1980 CONTINUE
       TEM2=CN+.5
       DO 2260 JJ=1,IC
       WH(JJ)=24.0-Z(JJ)
       IF(WH(JJ).LT.TEM2) GO TO 2240
      IF(DS(JJ) .GE. MAXSL)  GO TO 2240
       TEM1=MAXSL-DS(JJ)
       DS(JJ)=AMIN1(DS(JJ)+WH(JJ)-.5,MAXSL)
       TEM1=AMIN1(WH(JJ),TEM1)-.5
      IF(TEM1 .LE. 9.0)  GO TO 2205
 2200 FAT(JJ) = 0.0
      GO TO 2220
 2205 IF(TEM1 .LT. 1.0)  GO TO 2210
      FAT(JJ) = FAT(JJ)*((138.0-19.0*TEM1)/140.0+0.2*UNIFM1(0.0))
      GO TO 2220
 2210 FAT(JJ) = FAT(JJ)*(0.9-0.05*TEM1+0.2*UNIFM1(0.0))
 2220 IF(FAT(JJ) .LT. 0.0)  FAT(JJ) = 0.0
      IF(FAT(JJ) .GT. 1.0)  FAT(JJ) = 1.0
      ACAL(JJ) = 0.0
      TEM1 = FAT(JJ)
      IF(TEM1 .GT. 0.9)  GO TO 2225
      IF(TEM1 .GT. 0.15)  GO TO 2224
      HSLS(JJ) = 53.333333 * FAT(JJ)
       GO TO 2260
 2224 HSLS(JJ) = 14.666667*TEM1+5.8
```

```
      GO TO 2260
2225  HSLS(JJ)=AMAX1(310,0*TEM1-260.0,0.0)
      GO TO 2260
2240 HSLS(JJ) = HSLS(JJ) + WH(JJ)
     FAT(JJ) = FBUILD(HSLS(JJ))
2260 CONTINUE
      DO 2295 JJ=1,IC
     KK = IPS(JJ)
      TEM2=IEC(KK)    /PWR(JJ)
     IF (TEM2.GE.1.0) GO TO 2285
     EXER = 1.0
      GO TO 2290
2285 EXER = (ZPC-TEM2)/(ZPC-1.0)
2290 TEM1=(ACAL(JJ)/CAL(JJ))**2
     TEM1 = PC(JJ)*PI(JJ)*(1.0-(1.0-K1)*TEM1)*EXER*(1.0-0.1*FAT(JJ))
     IF (TEM1.LT.0.0) TEM1     = 0.0
     IF (TEM1.GT.2.0) TEM1     = 2.0
2295  PCC(JJ)=TEM1
     IF(NFALE .NE. 0)  SFDIFF=SFDIFF/FLOAT(NFALE)
      APA=APA/FLOAT(NSUC1+NSUC2+NFALE)
     CALL OUTP2
     IF(ND.GE.NDMAX) GO TO 2030
      ND=ND+1
      GO TO 650
2030  CALL OUTP3
     IF((ITAP .EQ. 1) .AND. (N .GT. 1))  ENDFILE 10
      NDAYS=NDAYS+ND
      IF(ITER.LT.N) GO TO 50
      CALL OUTP4
     GO TO 10
3000  WRITE(6,3001) ITEM
3001  FORMAT(26H1FATAL I/O ERROR FOR REC.-  I8)
     STOP
      END
COUTP1          SUBROUTINE OUTP1
      SUBROUTINE OUTP1
     INTEGER PI2
     COMMON/QCOM/PCOM(20),SCOM(20),IPS(20),ISS(20),TPCOM(20),TSCOM(20)
     COMMON/SEVENT/IETYP(570),TL(570),ST(570),EDCV(3,570),IPE(570),
    1 TS(570),TS1(570),NX(3,570),RTU(570),IFOI(570),IEFN(570),NIF(570)
    2  IEDC(3,570),PRB(3,570),NOSE,NEORE,NEME,DI(9)
      COMMON/OPP1/ IAA(4),PC(20),PACE(20),ASP(20),HSLS(20),PI(20)
    1,PI2(20),ICE(20)
      COMMON/OPP2/ TW(20),TWP(20),TWS(20),DS(20),APW(20),PCC(20),
    1               CASP(20),IDC(20),        NSUC1,NSUC2,NFALE,NIGNR,
    2 KONC(10),KONC1(10), SI,CML,ND,ITER,NDAYS,MPCC(20),FAT(20)
    3 ,STRM(20),CAL(20),PWR(20),CCAL(20),NU(20),PERF(20),NPRFM(4)
    4 ,APA,SFDIFF,CLSDTA(10,40)
      COMMON/OPP3/IC,FLIC,NREPT,HRSE,HRSR,HRSS,PEFF,
    1 MAXST,MAXSTE,USHT,NR,NTE,NE,TEH,CMLMX,ICML,SIDCMX,IDCMX,ICSS
     COMMON/OPP4/EPL(30),EDT(30),CART(30),CUT(30),
    1 AEPL,EPEFF,EMTBF,EMTTR,SRL,SPL,SGEM
     REAL MAXST,IITER ,JITER
     COMMON/IPARAM/APST,WORK1,WORK2,SLEEP,CN,MAXSL,TFAT,ACP,
    1CALRY,PWRRT,K7,K1,BE,AASP,KON(10),KONT(10,10),KON1(10),
    2 KONT1(10,10),SESTA(10),RELI(4),N,IET,IND(7),NDMAX
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```
      REAL IDC, KON, KONC, MPCC, NU, INTAB(13,21,10),KON1
       DIMENSION OUTA(35),TEM3(20),DALY(35,30),IITER(35,10),T3(10)
       DIMENSION TOUTA(13,10),NTIPE(10),TDALY(13,10,30),TIITER(13,10,10)
     1 ,ADALY(10,30), IDALY1(10,30),JITER(20,10),OUTB(20)
      DIMENSION CLSNME(37),CLSDTI(10,40),CLSDTR(10,40)
       DATA CLSNME/ 1HC ,1HO,1HD       ,1HA      ,2HEY     ,4HEURM  ,2HEC
     1 ,3HECA   ,2HER    ,2HEO    ,3HEIP   ,2HEI     ,4HERPT  ,5HELURM ,
     2 3HELC   ,3HELA   ,3HELR   ,3HELO   ,4HELEP  ,3HELI   ,5HELRPT ,
     3 5HEMURM ,3HEMC   ,3HEMA   ,3HEMR   ,3HEMO   ,4HEMEI  ,3HEMI   ,
     4 5HEMRPT  ,4HMURM  ,2HMC    ,2HMA    ,2HMR    ,2HMO    ,3HMEI   ,
     5 2HMI    ,4HMRPT    /
       DATA CI/6H       /
       DO 380 I=1,10
  380  NTIPE(I)=0
       DO 390 I=1,IC
       K=IPS(I)
  390  NTIPE(K)=NTIPE(K)+1
      IF(IND(2) .EQ. 0)  RETURN
       WRITE(6,9414)
 9414 FORMAT(17H1PRINT OPTION TWO/3H CE,7X,2HPC,5X,4HPCOM,5X,4HSCOM,5X,
     14HPACE,6X,3HASP,5X,4HHSLS,7X,2HPI)
      K = 0
      DO 420 I = 1,4
      KK = IAA(I)
      IF (KK.EQ.0) GO TO 420
      K = K+1
      PCA = PC(K)
      PCOMA = PCOM(K)
      SCOMA = SCOM(K)
      PACEA = PACE(K)
      ASPA = ASP(K)
      HSLSA = HSLS(K)
      PIA = PI(K)
      IF (KK.EQ.1) GO TO 415
      DO 410 J = 2,KK
      K = K+1
      PCA = PCA+PC(K)
      PCOMA = PCOMA+PCOM(K)
      SCOMA = SCOMA+SCOM(K)
      PACEA = PACEA+PACE(K)
      ASPA = ASPA+ASP(K)
      HSLSA = HSLSA+HSLS(K)
  410 PIA = PIA+PI(K)
      TEM1 = KK
      PCA = PCA/TEM1
      PCOMA = PCOMA/TEM1
      SCOMA = SCOMA/TEM1
      PACEA = PACEA/TEM1
      ASPA = ASPA/TEM1
      HSLSA = HSLSA/TEM1
      PIA = PIA/TEM1
  415 WRITE (6,9415)I,PCA,PCOMA,SCOMA,PACEA,ASPA,HSLSA,PIA
 9415 FORMAT(I3,7F9.3)
  420 CONTINUE
      WRITE(6,9416) (I,PC(I),PCOM(I),SCOM(I),PACE(I),ASP(I),HSLS(I),
     1 PI(I),PI2(I),FAT(I),STRM(I),CAL(I),PWR(I),ICE(I),IPS(I),ISS(I),
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```
      2 I=1,IC)
 9416 FORMAT(1H0/3H IC,7X,2HPC,5X,4HPCOM,5X,4HSCOM,5X,4HPACE,6X,3HASP,
     15X,4HHSLS,7X,2HPI,3X,3HPI2,6X,3HFAT,5X,4HSTRM,6X,3HCAL,6X,3HPWR,
     26H   ICE,6H   IPS,6H   ISS/(I3,7F9.3,I6,2F9.3,F9.0,F9.3,3I6))
      DO 425 I=1,12
 425  OUTA(I) = 0.0
      DO 430 I=1,IC
      OUTA(1) = OUTA(1)+PC(I)
      OUTA(2) = OUTA(2)+PCOM(I)
      OUTA(3) = OUTA(3)+SCOM(I)
      OUTA(4) = OUTA(4)+PACE(I)
      OUTA(5) = OUTA(5)+ASP(I)
      OUTA(6) = OUTA(6)+HSLS(I)
      OUTA(7) = OUTA(7)+PI(I)
      OUTA(8) = OUTA(8)+FLOAT(PI2(I))
      OUTA(9) = OUTA(9)+FAT(I)
      OUTA(10) = OUTA(10)+STRM(I)
      OUTA(11) = OUTA(11)+CAL(I)
 430  OUTA(12) = OUTA(12)+PWR(I)
      DO 435 I=1,12
 435  OUTA(I) = OUTA(I)/FLIG
      WRITE(6,9417) (OUTA(I),I=1,12)
 9417 FORMAT(9H0AVGS/MAN/3X,7F9.3,F6.2,2F9.3,F9.0,F9.3)

       TOUTA(3,K)=TOUTA(3,K)+TWS(I)
      RETURN
      ENTRY XXIN

      NREI=0
      CUTI=0.0
      CARTI=0.0
      CDTI=0.0
       DO 437 I=1,40
      DO 437 J=1,10
 437   CLSDTI(J,I)=0.0
       DO 460 I=1,10
       DO 440 J=1,35
 440   IITER(J,I)=0.0
       DO 460 KK=1,13
      DO 450 J=1,21
 450  IMTAB(KK,J,I) = 0.0
       DO 460 J=1,10
 460   TIITER(KK,J,I)=0.0
       RETURN
       ENTRY OUTP2
       DO 2000 J=1,13
       DO 1998 I=1,10
 1998  TOUTA(J,I)=0.0
 2000 OUTA(J)=0.0
       DO 2010 I=1,IC
       K=IPS(I)
       TEM3(I)=24.0-DS(I)-TW(I)
      IMTAB(1, I,ITER) = IMTAB(1, I,ITER) + PCC(I)
       OUTA(1)=OUTA(1)+PCC(I)
       TOUTA(1,K)=TOUTA(1,K)+PCC(I)
      IMTAB(2, I,ITER) = IMTAB(2, I,ITER) + TWP(I)
```

```
      OUTA(2)=OUTA(2)+TWP(I)
      TOUTA(2,K)=TOUTA(2,K)+TWP(I)
      IMTAB(3, I,ITER) = IMTAB(3, I,ITER) + TWS(I)
      OUTA(3)=OUTA(3)+TWS(I)
      IMTAB(4, I,ITER) = IMTAB(4, I,ITER) + DS(I)
      OUTA(4)=OUTA(4)+DS(I)
      TOUTA(4,K)=TOUTA(4,K)+DS(I)
      IMTAB(5, I,ITER) = IMTAB(5, I,ITER) + TEM3(I)
      OUTA(5)=OUTA(5)+TEM3(I)
      TOUTA(5,K)=TOUTA(5,K)+TEM3(I)
      IMTAB(6, I,ITER) = IMTAB(6, I,ITER) + FAT(I)
      OUTA(6)=OUTA(6)+FAT(I)
      TOUTA(6,K)=TOUTA(6,K)+FAT(I)
      IMTAB(7, I,ITER) = IMTAB(7, I,ITER) + PI(I)
      OUTA(7)=OUTA(7)+PI(I)
      TOUTA(7,K)=TOUTA(7,K)+PI(I)
      IMTAB(8, I,ITER) = IMTAB(8, I,ITER) + APW(I)
      OUTA(8)=OUTA(8)+APW(I)
      TOUTA(8,K)=TOUTA(8,K)+APW(I)
      IMTAB(9, I,ITER) = IMTAB(9, I,ITER) + PCOM(I)
      OUTA(9)=OUTA(9)+PCOM(I)
      TOUTA(9,K)=TOUTA(9,K)+PCOM(I)
      IMTAB(10, I,ITER) = IMTAB(10, I,ITER) + CASP(I)
      OUTA(10)=OUTA(10)+CASP(I)
      TOUTA(10,K)=TOUTA(10,K)+CASP(I)
      OUTA(11)=OUTA(11)+IDC(I)
      IMTAB(11, I,ITER) = IMTAB(11, I,ITER) + PERF(I)
      OUTA(12)=OUTA(12)+PERF(I)
      TOUTA(11,K)=TOUTA(11,K)+PERF(I)
      IMTAB(12, I,ITER) = IMTAB(12, I,ITER) + NU(I)
      TOUTA(12,K) = TOUTA(12,K)+NU(I)
2010  OUTA(13)=OUTA(13)+NU(I)
      DO 2020 I=1,13
      DO 2015 J=1,10
      K=NTIPE(J)
      IF (K.NE.  0) TOUTA(I,J)=TOUTA(I,J)/FLOAT(K)
2015  CONTINUE
      OUTA(I)=OUTA(I)/FLIC
2020  CONTINUE
      DALY(1,ND)=NSUC1
      DALY(2,ND)=NSUC2
      DALY(3,ND)=NFALE
      DALY(4,ND)=NIGNR
      DALY(5,ND)=OUTA(2)
      DALY(6,ND)=OUTA(3)
      DALY(7,ND)=OUTA(4)
      DALY(8,ND)=OUTA(5)
      DALY(9,ND)=KONC(1)
      DALY(10,ND)=KONC(2)
      DALY(11,ND)=KONC(3)
      DALY(12,ND)=OUTA(8)
      DALY(13,ND)=CML
      DALY(14,ND)=OUTA(9)
      DALY(15,ND) = APA
      DALY(16,ND)=OUTA(6)
      DALY(17,ND) = OUTA(10)
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      DALY(18,ND)=OUTA(7)
      DALY(19,ND)=SI
      DALY(20,ND) = NPRFM(3)
      DALY(21,ND) = NPRFM(4)
      DALY(22,ND)=NREPT
      DALY(23,ND) = HRSR
      DALY(24,ND) = HRSE
      DALY(25,ND) = MAXST
      DALY(26,ND) = CMLMX
      DALY(27,ND)=PEFF
      DALY(28,ND) = TEH
      DALY(29,ND) = SFDIFF
      DALY(30,ND) = NSUC1 + NSUC2
      DALY(31,ND) = USHT
      DALY (32,ND) = ICSS
      IQMAX = NEQRE
      DO 2034 I=1,IQMAX
      CUTI=CUTI + CUT(I)
      CDTI=CDTI + CDT(I)
2034  CARTI=CARTI + CART(I)
      NREI=NREI + NR
      DO 2032 I=1,10
      ADALY(I,ND) = KONC(I)
      IDALY1 (I,ND) = KONC1 (I)
2032  CONTINUE
      DO 2025 J=1,10
      DO 2025 I=1,12
2025  TDALY(I,J,ND)=TOUTA(I,J)
      DO 2022 I=1,40
      DO 2022 J=1,9
      CLSDTR(J,I)=CLSDTR(J,I) + CLSDTA(J,I)
2022  CLSDTI(J,I)=CLSDTI(J,I) + CLSDTA(J,I)
      IF(IND(6).GT.ND) RETURN
1990  NPRFM(1) = NPRFM(1)+NIGNR
      FNTE = NPRFM(1)
      N1S1=NSUC1+NSUC2
      TEM1=HRSS+HRSR+HRSE
      T3(1)=FLOAT(NFALE)/FNTE*100.0
      T3(2)=FLOAT(NSUC1)/FNTE*100.0
      T3(3)=FLOAT(NSUC2)/FNTE*100.0
      T3(4)=FLOAT(NIGNR)/FNTE*100.0
      T3(5)=FLOAT(NREPT)/FNTE*100.0
      WRITE(6,9984) ND,ITER,(NPRFM(I),I=1,4),NREPT,N1S1,NFALE,NIGNR,
     1 TEM1,HRSS,HRSR,HRSE,USHT,APA,SFDIFF,
     1 (T3(I),I=1,5),SI,CI,CML,PEFF,TEH,
     2                MAXST,MAXSTE,CMLMX,ICML,SIDCMX,IDCMX,ICSS
     3 ,(KONC1(I),I=1,10), (KONC(I),I=1,10)
9984  FORMAT(15H1REPORT FOR DAYI3,11H  ITERATIONI3/19H  NO. EVENTS--TOT
     1LI4,12H   SCHEDULEDI4,9H   REPAIRI4,12H   EMERGENCYI4,10H   REPEA
     2SI4,12H   SUCCESSESI4,11H   FAILURESI4,10H   IGNORESI4/22H  HOURS
     3WORKED---TOTALF6.1,11H  SCHEDULEDF6.1,8H  REPAIRF6.1,7H  EMER.
     4F6.1,10H  UNMANNEDF7.1,15H  AVG PERF ADEQF5.2,14H AVG FAIL DIFF
     5 F6.3/  25H  PERCENTAGE OF---FAILUREF5.1,             15H  SUC
     6, 1ST TRYF5.1,15H  SUCC, 2ND TRYF5.1,9H  IGNOREDF5.1,9H  REPEATSF
     7,1/14H  SAFETY INDEXF6.2,16(1H ),1A6,13H  MENTAL LOAD
     8 F8.2,10H  PERF EFF F9.3,6H  HAZ. F7.0,12H                    /
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    913H  MAX. STRESSF6.2,9H ON EVENTI4,18H  MAX. MENTAL LOADF4.0,
    A9H ON EVENTI4,20H  MAX. CAL. EXPENDEDF9.0,9H ON EVENTI4,10H SEA ST
    BATE I3/20H CONS. BAL. (UNITS) 1017  ,/23H CONS. BAL. (UNITS/HR) 1C
    C F7.0)
      WRITE(6,9985)
9985 FORMAT(125H0MAN  TYPE  PHYSICAL  HOURS WORKED  SLEPT  IDLE  FATIGU
    1E  HEALTH  AVG PHYS  COMPETENCE  ASPIRATION   PERFORM  NUMBER
    2    /4H NO.,10X,4HCAP,4X,12HPRIM,     2ND,25X,5HINDEX,2X,8HWORKLOAD
    329X,4HCUM.,4X,5HSUCC.)
      DO 1991 I=1,IC
      WRITE(6,9987) I,IPS(I),PCC(I),TWP(I),TWS(I),DS(I),TEM3(I),FAT(I),
    1PI(I),APW(I),PCOM(I),BASP(I),        PERF(I),NU(I)
9987 FORMAT(1H ,I3,I6,F10.3,2F7.2,F7.1,F6.1,F9.2,F8.2,F10.2,F12.3,
    1F12.2,       F9.2,F8.0)
1991  CONTINUE
      WRITE(6,9988) (OUTA(I),I=1,10),OUTA(12),OUTA(13)
9988  FORMAT(9H0AVERAGES/9H  PER MANF11.3,2F7.2,F7.1,F6.1,F9.2,F8.2,
    1 F10.2,F12.3,F12.2,F9.2,F10.2)
      WRITE(6,9989)
9989 FORMAT(1H0//17H0AVERAGES BY TYPE/11H   NO  TYPE)
      DO 1995 I=1,10
      K=NTIPE(I)
      IF(K.EQ.0) GO TO 1995
      WRITE(6,9990) K,I,(TOUTA(J,I),J=1,12)
9990  FORMAT(2I5,   F10.3,2F7.2,F7.1,F6.1,F9.2,F8.2,F10.2,F12.3,F12.2,
    1 F9.2,F8.2)
1995  CONTINUE
      WRITE(6,1996) (I,CART(I),CDT(I),CUT(I),EPL(I),I=1,IQMAX)
1996  FORMAT(//1H0,25X,32HDAILY EQUIPMENT PERFORMANCE DATA  //
    1 27H IQ  CART   CDT   CUT   EPL  /(I3,4F6.2))
      WRITE(6,1997) AEPL,EPEFF,EMTBF,EMTTR,SRL,SPL,SGEM
1997  FORMAT(//6H AEPL=F6.2,4X,6HEPEFF=F6.2,4X,6HEMTBF=F6.2,
    1  4X,6HEMTTR=F6.2,4X,4HSRL=F6.2,4X,4HSPL=F6.2,4X,5HSGEM=F6.2)
      WRITE(6,2159)
2159  FORMAT(//1H0,30X,24HSUMMARY BY EVENT CLASS       /
    1 85 H CLASS  TOT PERF  HRS PRIM  HRS SEC  SUC1  SUC2  FAIL  IGNORE
    1  PERF AD  AV FAIL DIFF    )
      DO 40 I=1,40
      IF(CLSDTA(1,I).LE.0.0) GO TO 40
      DO 30 J=2,9
  30  CLSDTA(J,I)= CLSDTA(J,I)/CLSDTA(1,I)
      WRITE(6,2160) I,CLSDTA(1,I),CLSDTA(6,I),CLSDTA(7,I),CLSDTA(2,I),
    1 CLSDTA(3,I),CLSDTA(4,I),CLSDTA(5,I),CLSDTA(8,I),CLSDTA(9,I)
2160  FORMAT(I6,F10.0,F10.2,F9.2,3F6.2,F8.2,F9.2,F12.2)
  40  CONTINUE
      RETURN
      ENTRY OUTP3
2030 WRITE(6,9029) ITER,NDMAX
9029 FORMAT(21H1REPORT FOR ITERATIONI3,3H OFI3,15H DAY MISSION---/
    2 127H DAY     NUMBER OF EVENTS        AVE. MAN HOURS SPENT
    3                    ----------END OF DAY AVERAGES----------  INDICE
    4/5X,125H SUC1 SUC2 FAIL IGNORE  PRIM. SECOND  SLEEP   IDLE
    5                   PHYS LD  MEN LD  COMP  APA   FAT.  ASP  HLTH  SF
    6Y/)
      DO 2031 J=1,NDMAX
2031 WRITE (6,9030) J, (DALY(I,J),I=1,8),(DALY(I,J),I=12,19)
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```
 9030 FORMAT (I4,1X,3F5.0,F7.0,4F7.2,24X,  F8.2,F8.2,F6.3,F6.2,
     1 F6.2,F5.2,2F6.2)
       FD=NDMAX
       TOT=0.0
       DO 2055 I=1,NDMAX
       DO 2055 J=1,4
       TOT=TOT+DALY(J,I)
 2055 IITER(J,ITER)=IITER(J,ITER)+DALY(J,I)
       DO 2056 J=1,4
 2056 IITER(J,ITER)=IITER(J,ITER)/TOT*100.0
       DO 2058 J=5,8
       DO 2057 I=1,NDMAX
 2057 IITER(J,ITER)=IITER(J,ITER)+DALY(J,I)
 2058  IITER(J,ITER)=IITER(J,ITER)/FD
      DO 2061 I=1,10
      JITER(I,ITER) = KONC(I)/KON(I) *100.0
      ZTEM = KONC1(I)
      JITER(I+10,ITER) = ZTEM    /KON1(I) *100.0
 2061 CONTINUE
      DO 2060 J=12,19
      DO 2059 I=1,NDMAX
 2059 IITER(J,ITER)=IITER(J,ITER)+DALY(J,I)
 2060  IITER(J,ITER)=IITER(J,ITER)/FD
       WRITE(6,9031) (IITER(I,ITER),I=1,8),(IITER(I,ITER),I=12,19)
 9031  FORMAT(1H /5X,22H---PERCENT OF TOTAL---6X,15HAVERAGE PER DAY7X,
     1 24H                        18X,15HAVERAGE PER DAY/
     2 5X,3F5.1,F7.1,4F7.2,24X,  2F8.2,F6.3,F6.2,F6.2,F5.2,2F6.2)
      DO 3010 J=1,NDMAX
      WRITE(6,3040) (ADALY(I,J),I=1,10)
 3040 FORMAT(24H CONS. BAL. (UNITS/HR)  10F7.0)
 3010 CONTINUE
      WRITE (6,3050) (JITER(J,ITER),J=1,10)
 3050 FORMAT(24H PERCENT OF ORIGINAL    10F7.3)
      DO 3020 J=1,NDMAX
      WRITE (6,3030) (IDALY1(I,J),I=1,10)
 3030 FORMAT(24H CONS. BAL. (UNITS)     10I7)
 3020 CONTINUE
      WRITE (6,3050) (JITER(J,ITER),J=11,20)
      WRITE(6,90315)
90315 FORMAT  (/131H DAY     NUMBER OF EVENTS   AVE. MAN HOURS SPENT
     1AX STRESS  MAX MEN LD   PERF EFF  HAZARD  AVG FL DIFF  NUMBER  UNI
     2ANNED   SEA  / 8X,38HREPAIR EMER   REPT    REPAIR EMERGENCY,63X,
     3 5HSUCC.,3X,5HHOURS,2X,6H STATE)
      DO 2062 J=1,NDMAX
      WRITE(6,90316) J,(DALY(I,J),I=20,32)
      DO 2062 I=20,32
 2062 IITER(I,ITER) = IITER(I,ITER)+DALY(I,J)
90316  FORMAT(I4,1X,F9.1,F6.1,F6.1,F9.1,F13.1,F12.2,F12.2
     1 F12.3,F8.2,F13.3,F8.2,F10.2,F5.1)
      DO 2063 I=20,29
 2063 IITER(I,ITER) = IITER(I,ITER)/FD
      IITER (32,ITER) = IITER (32,ITER)/FD
      IITER(31,ITER) = IITER(31,ITER)/FD
90317  FORMAT(/9H0AVGS/DAYF6.1,2F6.1,F8.1,F13.1,F12.2,F12.2,
     1 F12.3,F8.2,F13.3,F10.2,F10.2,F5.1)
      WRITE(6,90317) (IITER(I,ITER),I=20,32)
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```
      WRITE(6,9034)
9034 FORMAT( ///  30HOAVERAGES BY TYPE OF PERSONNEL/)
      WRITE(6,9032)
9032  FORMAT(   125H0     TYPE  PHYSICAL  HOURS WORKED  SLEPT  IDLE  F/
     1TIGUE  HEALTH  AVG PHYS  COMPETENCE  ASPIRATION            PERFORI
     2  NUMBER/4H NO.,10X,4HCAP,4X,12HPRIM.     2ND,25X,5HINDEX,2X,
     3 8HWORKLOAD,38X,4HCUM.,4X,5HSUCC.)
      DO 2065 I=1,NDMAX
      DO 2065 J=1,10
      K=NTIPE(J)
      IF(K.EQ.0) GO TO 2065
9033  FORMAT(1H I3,I6,F10.3,2F7.2,F7.1,F6.1,F9.2,F8.2,F10.2,F12.3,
     1 F12.2,10X,F9.2,F8.2)
      DO 2064  KK=1,12
2064  TIITER(KK,J,ITER)=TIITER(KK,J,ITER)+TDALY(KK,J,I)
2065  CONTINUE
      DO 2067 J=1,10
      K=NTIPE(J)
      IF(K.EQ.0) GO TO 2067
      DO 2066 I=1,11
2066  TIITER(I,J,ITER)=TIITER(I,J,ITER)/FD
     WRITE(6,9991)K,J,(TIITER(I,J,ITER),I=1,12)
9991  FORMAT(2I5    ,F10.3,2F7.2,F7.1,F6.1,F9.2,F8.2,F10.2,F12.3,F12.2,
     1 10X,F9.2,F8.2)
2067  CONTINUE
2070  CONTINUE
     T3(1)=CUTI/(CUTI+CDTI)
     T3(2)=CARTI/FLOAT(NREI)
     REMTB=REMTB + T3(1)
     REMTR=REMTR + T3(2)
     IF(IND(7).EQ.0) RETURN
     WRITE(6,9275)
9275 FORMAT(30HOAVERAGES PER DAY FOR EACH MAN/)
     DO 2072 I=1,12
2072 OUTA(I)=0.0
     DO 2080 I=1,IC
     DO 2075 J=1,12
     IMTAB(J,I,ITER) = IMTAB(J,I,ITER)/FD
2075 OUTA(J)=OUTA(J)+IMTAB(J,I,ITER)
2080 WRITE(6,9991) I,IPS(I),(IMTAB(J,I,ITER),J=1,12)
     DO 2082 I=1,12
2082 OUTA(I)=OUTA(I)/FLIC
     WRITE(6,9996) (OUTA(I),I=1,12)
9996 FORMAT(10HOAVERAGES
     1                   F10.3,2F7.2,F7.1,F6.1,F9.2,F8.2,F10.2,F12.3,F12.2,
     1 10X,F9.2,F8.2)
      WRITE(6,9997) T3(1), T3(2)
9997  FORMAT(//7HOEMTBF= F8.3,5X,6HEMTTR= F8.3)
     WRITE(6,2159)
      DO 2084 I=1,40
     IF( CLSDTI(1,I).LE. 0.0) GO TO 2084
     DO 2083 J=2,9
2083  CLSDTI(J,I)= CLSDTI(J,I) / CLSDTI(1,I)
     WRITE(6,2160) I,CLSDTI(1,I),CLSDTI(6,I),CLSDTI(7,I),CLSDTI(2,I),
     1 CLSDTI(3,I),CLSDTI(4,I),CLSDTI(5,I),CLSDTI(8,I),CLSDTI(9,I)
2084  CONTINUE
```

```
      RETURN
       ENTRY OUTP4
       FLITER=ITER
       WRITE(6,9555) ITER,NDMAX
 9555  FORMAT(16H1RUN SUMMARY FORI3,14H ITERATIONS OFI3,12H-DAY MISSION/
     1 127H ITER    NUMBER OF EVENTS       AVE. MAN HOURS SPENT
     1                   ----------END OF DAY AVERAGES----------  INDICES
     2/5X,125H SUC1 SUC2 FAIL IGNORE  PRIM. SECOND  SLEEP   IDLE
     3                  PHYS LD  MEN LD  COMP   APA  FAT.  ASP  HLTH  SF1
     4Y/5X,22H---PERCENT OF TOTAL---6X,15HAVERAGE PER DAY7X,
     5 24H                        18X,15HAVERAGE PER DAY)
       DO 2105 I=1,32
 2105  OUTA(I)=0
       DO 2110 I=1,ITER
       WRITE(6,9556) I,(IITER(J,I),J=1,8),(IITER(J,I),J=12,19)
 9556 FORMAT(1X,I4,3F5.1,F7.1,4F7.2,24X, 2F8.2,F6.3,F6.2,F6.2,F5.2,
     12F6.2)
      DO 2108 J=1,32
 2108  OUTA(J)=OUTA(J)+IITER(J,I)
      DO 2109 J=1,10
      OUTB(J) = OUTB(J) + JITER(J,I)
      OUTB (J+10) = OUTB(J+10) + JITER(J+10 ,I)
 2109 CONTINUE
 2110 CONTINUE
       DO 2115 J=1,32
 2115  OUTA(J)=OUTA(J)/FLITER
       WRITE(6,9557) (OUTA(I),I=1,8),(OUTA(I),I=12,19)
 9557 FORMAT (19H0AVERAGES/ITERATION/
     1          5X,3F5.1,      5F7.2,24X,  F8.2,F8.2,F6.3,F6.2,F6.2,F5.2,
     2 2F6.2)
      DO 2150 I=1,ITER
      WRITE (6,3070)I,(JITER(J,I),J=1,10)
 3070 FORMAT(6H ITER I2,44H CONS. BAL. (UNITS/HR) PERCENT OF ORIGINAL
     1 10F7.3)
      WRITE (6,3060) I, (JITER(J,I),J=11,20)
 3060 FORMAT(6H ITER I2,44H CONS. BAL. (UNITS) PERCENT OF ORIGINAL
     1 10F7.3)
 2150 CONTINUE
      WRITE(6,3080) (OUTB(I),I=1,10)
 3080 FORMAT(37H AVERAGE CONSUMABLE USAGE (UNITS/HR) ,16X,10F7.2)
      WRITE (6,3090) (OUTB(I),I=11,20)
 3090 FORMAT(34H AVERAGE CONSUMABLE USAGE (UNITS) ,19X,10F7.2)
      WRITE(6,9115)
 9115 FORMAT (//131H ITER    NUMBER OF EVENTS   AVE. MAN HOURS SPENT   M
     1AX STRESS  MAX MEN LD   PERF EFF  HAZARD  AVG FL DIFF  NUMBER  UN
     2MANNED   SEA / 8X,38HREPAIR EMER   REPT    REPAIR EMERGENCY,63X,
     3 5HSUCC.,5X,5HHOURS,6H STATE)
      WRITE(6,90316) (I,(IITER(J,I),J=20,32),I=1,ITER)
      WRITE(6,90318) (OUTA(I),I=20,32)
90318  FORMAT(19H0AVERAGES/ITERATION/
     1 8X,3F6.1,F9.1,F13.1,F12.2,F12.2,F12.3,F8.2,F13.3,F8.2,F10.2,F5.1)
      DO 2120 I=1,11
      DO 2120 J=1,10
 2120 TOUTA(I,J) = 0.0
 9120 FORMAT(///30H0AVERAGES BY TYPE OF PERSONNEL/)
      WRITE(6,9120)
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      WRITE(6,9558)
 9558 FORMAT (    125H0      TYPE  PHYSICAL  HOURS WORKED  SLEPT  IDLE  F
     1TIGUE  HEALTH  AVG PHYS  COMPETENCE  ASPIRATION  PERFORM
     2        /14X        ,4HCAP.4X,12HPRIM.     2ND.25X,5HINDEX,2X,
     3 8HWORKLOAD,30X,4HCUM,)
       DO 2125 I=1,ITER
       DO 2124 J=1,10
       IF(NTIPE(J).EQ.0) GO TO 2124
       DO 2123 K=1,11
 2123  TOUTA(K,J)=TOUTA(K,J)+TIITER(K,J,I)
 2124  CONTINUE
 2125  CONTINUE

      DO 2140 J=1,10
      IF(NTIPE(J) .EQ. 0)  GO TO 2140
      DO 2130 I=1,11
 2130 TOUTA(I,J) = TOUTA(I,J)/FLITER
      WRITE(6,9993)       J,(TOUTA(I,J),I=1,11)
 9993  FORMAT(5X,I5, F10.3,2F7.2,F7.1,F6.1,F9.2,F8.2,F10.2,F12.3,F12.2,
     1 F9.2,F8.2)
 2140 CONTINUE
      WRITE(6,2159)
      DO 2144 I=1,40
      IF(CLSDTR(1,I).LE.0.0) GO TO 2144
      DO 2143 J=2,9
 2143 CLSDTR(J,I) = CLSDTR(J,I) / CLSDTR(1,I)
      WRITE(6,2160) I,CLSDTR(1,I),CLSDTR(6,I),CLSDTR(7,I),CLSDTR(2,I),
     1 CLSDTR(3,I),CLSDTR(4,I),CLSDTR(5,I),CLSDTR(8,I),CLSDTR(9,I)
 2144  CONTINUE
      T3(1) = OUTA(1)/(OUTA(1)+OUTA(2)+OUTA(3)) + (OUTA(5)+OUTA(6))
      T3(2) = OUTA(2)*(OUTA(5)+OUTA(6))
      T3(3) = T3(1)/(T3(1) + T3(2))
      T3(4) = REMTB
      T3(5) = REMTR
      T3(6) = T3(4)/(T3(4) + T3(5))
      T3(7) = SQRT(0.5*(T3(3)**2 + T3(6)**2))
      WRITE(6,9140) (T3(I),I=1,7)
 9140 FORMAT(1H0,9HHMTBF    =,F8.3,5X,8HHMTTR  =,F8.3,
     1 5X,9HHAVAIL  =,F8.3/
     2 1X,9HEMTBF   =,F8.3,5X,8HEMTTR  =,F8.3,5X,8HEAVAIL =,F8.3/
     3 1X,9HSYSAVAIL=,F8.3)

       RETURN
       END
CFBLD          FUNCTION FBUILD
       FUNCTION FBUILD(H)
       HSLS=H
       TEM1=0.2*UNIFM1(0.0)
       IF(HSLS.LT.8.0) GO TO 20
       IF(HSLS.LT.19.0) GO TO 10
       FBUILD=(HSLS+229.0)/810.0+TEM1
       GO TO 5000
   10   FBUILD=(15.0*HSLS-109.0)/220.0+TEM1
       GO TO 5000
C////////////////////////////////
   20 FBUILD = 0.01875 * HSLS - 0.1 * TEM1
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```
 5000 IF(FBUILD .GE. 0.0)  GO TO 5002
      FBUILD = 0.0
      GO TO 5555
 5002 IF(FBUILD .GT. 1.0)  FBUILD = 1.0
 5555 RETURN
       END
CIPUY          FUNCTION IPUYSM
       FUNCTION IPUYSN(PAR)
       TEST=EXP(-PAR)
       K=0
       Y=UNIFM1(0.0)
 1000 IF(Y.LE.TEST) GO TO 5800
       K=K+1
       Y=Y*UNIFM1(0.0)
       GO TO 1000
 5000 IPUYSN=K
       RETURN
       END
CPSCAP         SUBROUTINE PSCAP
      SUBROUTINE PSCAP(IAA,PCDUM,PSCOM)
      DIMENSION IAA(4),PCDUM(6),PSCOM(40),TEM(3),L(3),LL(3),DATR(3)
      DATA DATR/0.95,0.75,0.60/
      NN=1
      DO 350 I=1,4,3
      DO 340 J=1,4
      L1=IAA(J)
      TEM1=L1
      KI=I
      DO 110 K=1,3
      TEM(K)=TEM1*PCDUM(KI)
      L(K)=TEM(K)
      KI=KI+1
  110 L1=L1-L(K)
      IF(L1.EQ.0)GO TO 275
      KI=I
      DO 130 K=1,3
       TEM(K)=TEM(K)-FLOAT(L(K))
       IF(TEM(K).LT.(.5)) GO TO 130
      L(K)=L(K)+1
      L1=L1-1
      IF(L1.EQ.0)GO TO 275
  130 CONTINUE
       DO 135 K=1,3
  135 LL(K)=K
      DO 150 K=1,2
      KK=3-K
      DO 140 II=1,KK
      IF(TEM(II).GE.TEM(II+1))GO TO 140
      TEMP=TEM(II)
      LT=LL(II)
      TEM(II)=TEM(II+1)
      TEM(II+1)=TEMP
      LL(II)=LL(II+1)
      LL(II+1)=LT
  140 CONTINUE
  150 CONTINUE
```

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      DO 160 K=1,3
      KK=LL(K)
      L(KK)=L(KK)+1
      L1=L1-1
      IF(L1.EQ.0)GO TO 275
  160 CONTINUE
      KK=LL(1)
      L(KK)=L(KK)+L1
  275 DO 310 K=1,3
      KK=L(K)
      IF(KK.EQ.0)GO TO 310
      TEMP = DATR(K)
      DO 305 N=1,KK
       PSCOM(NN)=AMIN1(.99,TEMP+DNORM1(0.0)*0.03)
  305 NN=NN+1
  310 CONTINUE
  340 CONTINUE
  350 NN=21
      RETURN
      END
CINPUT         SUBROUTINE INPUT
      SUBROUTINE INPUT(ITER,KASE)
      COMMON/PRSNEL/WT,SIGWT,PPFQ,PPMQ,PPUQ,SPFQ,SPMQ,SPUQ,
     1MPI,PID,ZPC,PTT(10,10),MEN(10,4),NDS,IDS(6,20)
      COMMON/IPARAM/APST,WORK1,WORK2,SLEEP,CN,MAXSL,TFAT,ACP,
     1CALRY,PWRRT,K7,K1,BE,AASP,KON(10),KONT(10,10),KON1(10),
     2 KONT1(10,10),SESTA(10),RELI(4),N,IET,IND(7),NDMAX
      COMMON/EQREVNT/ IDF(30),RELH(30),DTR(570),TUI(30),IRE(30)
      COMMON/EEMER/ART(10),ASDE(10),DTE(10),IESSE(10) ,NREQE(10,10),
     1 LODME(10),IRCE(10,10),IRCE1(10,10),TSE(10),TSE1(10),IHE(10),
     1 IECE(10,10),DTBE(10),NDBE(10)
      COMMON/ETYPE/ADUR,ASD,IESS,NREQ(10),LODM,KE,INT,IRC(10),IRC1(10),
     1 IH,IEC(10),NTQR,IQR(6),ICLASS
      COMMON/SEVENT/IETYP(570),TL(570),ST(570),EDCV(3,570),IPE(570),
     1 TS(570),TS1(570),NX(3,570),RTU(570),IFOI(570),IEFN(570),NIF(570)
     2  IEDC(3,570),PRB(3,570),NOSE,NEQRE,NEME,DI(9)
       DIMENSION FP1(111),IP1(161),FP2(248),IP2(9),FP3(2200),IP3(2200),
     1 FP4(3660),IP4(3800),FP5(600),IP5(2000),DUMY(12),IDES(12)
      DIMENSION PTTT(10,10)
      DIMENSION ADURIO(55)
      EQUIVALENCE(ADURIO,ADUR)
      EQUIVALENCE (WT,FP1),(MEN,IP1),(APST,FP2),(N   ,IP2),
     1 (FP3,FP4),(FP3,FP5),(IP3,IP4),(IP3,IP5),(IP3,IGBG),(FP3,GBG)
      INTEGER TS,TS1,RTU,TSE,TSE1,TSR,TSR1
      REAL MPI,MAXSL,K7,K1,IEC,LODM,IH,IRC,KON,KON1,KONT,KONT1
       REAL IECE,IHE,IRCE,LODME
      NAMELIST/PERSNL/NFP1,FP1,NIP1,IP1
      NAMELIST/PARAM/NFP2,FP2,NIP2,IP2
      NAMELIST/SCHEVT/NFP3,FP3,NIP3,IP3
      NAMELIST/EQREVT/NFP4,FP4,NIP4,IP4
      NAMELIST/EMREVT/NFP5,FP5,NIP5,IP5
      NAMELIST/TYPE/ NFP5,FP5,NIP5,IP5
      IERR = 0
      IF(ITER .GT. 1)  GO TO 225
  100 NFP2 = 0
      NIP2 = 0
```

```
      READ (5,PARAM)
      IF((NFP2,NE.248),OR,(NIP2,NE,9)) GO TO 9010
101   WRITE(6,8100) (FP2(I),I=1,248),(IP2(I),I=1,9)
8100  FORMAT (7H1APST =F13.2,8H  WORK1=F14.1,8H  WORK2=F14.1,8H  SLEEP=F
     114.1,8H  CN    =F14.1,8H  MAXSL=F14.1/7H0TFAT =F13.2,8H  ACP   =F14.
     22,8H  CALRY=F14.0,8H  PWRRT=F14.1,8H  K7    =F14.2,8H  K1    =F14.2/
     37H0BE    =F13,2,8H   AASP=F14.2//
     314H0KON(1-10)    =10F9,0/15H  KONT(1-10)  =  /10(14X,10F9.0/),
     4 /14H0KON1(1-10)  = 10F9.0/  15H  KONT1(1-10) =  /10(14X,10F9.0/),
     5  13H SESTA(0-09)=10F5.2/11H0RELI(1-4)=4F8.2/
     6 3H0N=I5,6H  IET=I5,11H  IND(1-7)=7I3)
200   IF(KASE .LE. 1)  GO TO 201
      DO 205 I=1,10
      DO 205 J=1,10
      PTT(I,J) = PTTT(I,J)
205   CONTINUE
201   NFP1 = 0
      NIP1 = 0
      READ (5,PERSNL)
      IF ((NFP1.NE.111).OR.(NIP1.NE.161)) GO TO 9020
      IF(KASE .NE. 1)  GO TO 209
      DO 208 I=1,10
      DO 208 J=1,10
      PTTT(I,J) = PTT(I,J)
208   CONTINUE
209   DO 220 I=1,10
      DO 210 J=2,10
      PTT(J,I)=PTT(J,I)+PTT(J-1,I)
210   CONTINUE
220   CONTINUE
225   IF(IND(1) .EQ. 0  .OR,  ITER .GT, 1)  GO TO 299
      WRITE (6,8200)(FP1(I),I = 1,111),( IP1(I),I = 1,161)
8200  FORMAT (7H1WT    =F7.1,8H  SIGHT=F7.1/7H PPFQ =F7.2,8H  PPMQ =F7.2,
     18H  PPUQ =F7.2/7H SPFQ =F7.2,8H  SPMQ =F7.2,8H  SPUQ =F7.2/7H MPI
     2 =F7.2,8H  PID   =F7.1,8H  ZPC   =F7.2/14H0PTT(1-10,1) =10F5.2,15H
     3PTT(1-10,2) =10F5.2/14H PTT(1-10,3) =10F5.2,15H  PTT(1-10,4) =10F5
     4,2/14H PTT(1-10,5) =10F5.2,15H  PTT(1-10,6) =10F5.2/14H PTT(1-10,7
     5) =10F5.2,15H  PTT(1-10,8) =10F5.2/14H PTT(1-10,9) =10F5.2,15H  PT
     6T(1-10,10)=10F5.2//13H0MEN(1-10,1)=10I4,14H  MEN(1-10,2)=10I4/13H
     7MEN(1-10,3)=10I4,14H  MEN(1-10,4)=10I4/15H0NO. OF SHIFTS=,I6/,
     813H IDS(1-6, 1)=,6I4,5X,12HIDS(1-6, 2)=,6I4,5X,12HIDS(1-6, 3)=6I4/
     913H IDS(1-6, 4)=,6I4,5X,12HIDS(1-6, 5)=,6I4,5X,12HIDS(1-6, 6)=6I4/
     A13H IDS(1-6, 7)=,6I4,5X,12HIDS(I-6, 8)=,6I4,5X,12HIDS(1-6, 9)=6I4/
     B13H IDS(1-6,10)=,6I4,5X,12HIDS(I-6,11)=,6I4,5X,12HIDS(1-6,12)=6I4/
     C13H IDS(1-6,13)=,6I4,5X,12HIDS(I-6,14)=,6I4,5X,12HIDS(1-6,15)=6I4/
     D13H IDS(1-6,16)=,6I4,5X,12HIDS(I-6,17)=,6I4,5X,12HIDS(1-6,18)=6I4/
     E13H IDS(1-6,19)=6I4,5X,12HIDS(1-6,20)=6I4)
299    IF(ITER,EQ.1) GO TO 300
      REWIND 10
       READ(10) NFP4,NIP4,NEQRE,(FP4(I),I=1,NFP4),(IP4(I),I=1,NIP4)
       GO TO 301
300   NFP4 = 0
      NIP4 = 0
      READ (5,EQREVT)
      NEQRE=IP4(1)
      IF(N .LE. 1)  GO TO 301
```

```
      REWIND 10
      WRITE(10) NFP4,NIP4,NEQRE,(FP4(I),I=1,NFP4),(IP4(I),I=1,NIP4)
  301 KK = 2
      MM = 1
      IF (IND(1) .NE. 0 .AND. ITER .LE. 1) WRITE (6,8329)
 8329 FORMAT(1H1,90X,27HEQUIPMENT REPAIR EVENT DATA/
     1 111H  IQ   DESCRIPTION
     2                   TSR,   TSR1        RELH     TUI  IRE   /
     3 98H TYPE  NX(1-3)       PRB(1-3)    RTU IEDC(1-3)    IEDCV(1-3)
     2               IPE  IFOI          IEFN  DTR)
      DO 350 I = 1,NEQRE
      DO 305 J=1,12
       IDES(J)=IP4(KK)
  305  KK=KK+1
      TSR = IP4 (KK)
      TSR1 = IP4 (KK + 1)
      IREX=IP4(KK+2)
      IRE(I)=IREX
      IEFNX=IP4(KK+3)
      KK=KK+3
      RELH(I)=FP4(MM)
      TUI(I)=FP4(MM+1)
C     DTR(I)=FP4(MM+2)
      MM=MM+2
      J=200+(I-1)*12
      ITEM=J
      DO 310  JJ=1,IREX
      J=J+1
      TS(J)=TSR
      TS1(J)=TSR1
      IETYP(J) = IP4 (KK + 1)
      IPE(J) = IP4 (KK + 2)
      IF(IPE(J).NE.0) IPE(J)=IPE(J)+ITEM
      NX (1,J) =  IP4 (KK + 3)
      NX (2,J) =  IP4 (KK + 4)
      NX(3,J) =   IP4 (KK + 5)
      NX(1,J)=NX(1,J)+ITEM
      NX(2,J)=NX(2,J)+ITEM
      NX(3,J)=NX(3,J)+ITEM
      RTU(J) =    IP4 (KK + 6)
      IFOI(J) =   IP4 (KK + 7)
      IEFN(J)=IEFNX
      DTR(J)=FP4(MM)
      PRB(1,J) = FP4 (MM + 1)
      PRB(2,J) = FP4 (MM + 2)
      PRB(3,J)= FP4 (MM + 3)
      IEDC(1,J)=FP4(MM+4)
      IEDC(2,J)=FP4(MM+5)
      IEDC(3,J)=FP4(MM+6)
      EDCV(1,J)=FP4(MM+7)
      EDCV(2,J)=FP4(MM+8)
      EDCV(3,J)=FP4(MM+9)
      ST(J) = 0.0
      TL(J) = 24.0
       KK=KK+7
      MM=MM+10
```

```
  310 CONTINUE
      JJ=J
      KK = KK + 1
C     MM = MM + 1
      II=J-IREX+1
      IF (IND(1) .NE. 0 .AND. ITER .LE. 1) WRITE(6,8330)
     1 I,IDES,TSR,TSR1,RELH(I),TUI(I),  IREX,(IETYP(J),(NX(K,J),K=1,3),
     2 (PRB(K,J),K=1,3),RTU(J),(IEDC(K,J),K=1,3),
     3 (EDCV(K,J),K=1,3),IPE(J),IFOI(J),IEFN(J),DTR(J),J=II,JJ)
 8330 FORMAT(1H0/I3,2X,12A6,I3,I6,F10.6,F7.2,I5/
     1 (1H ,I3,1X,I3,2I4,3F5.2,2I2, 2I3,1X,3F10.3,I3,I6,I11,F5.2))
  350 CONTINUE
  399  IF(ITER.EQ.1) GO TO 400
       NFP5=NEME*3
      NIP5=NEME*47
       READ(10) (FP5(I),I=1,NFP5),(IP5(I),I=1,NIP5)
       GO TO 401
  400 NFP5 = 0
      NIP5 = 0
      READ (5,EMREVT)
      NEME = NFP5/3
      NFP3=NIP5/58
      IF((NFP5.NE.NEME*3).OR.(NIP5.NE.NFP3*58)) GO TO 9040
       IF(N.GT.1) WRITE(10) (FP5(I),I=1,NFP5),(IP5(I),I=1,NIP5)
  401 KK = 1
      MM = 1
      IF (IND(1) .NE. 0 .AND. ITER .LE. 1) WRITE(6,8429)
 8429 FORMAT(1H1,90X,20HEMERGENCY EVENT DATA/18H   K    IDENTIFIER/
     1 23H  NDBE  ART   ASDE  DTE,58X,10HIRCE(1-10),10X,3HTSE,3X,5HLODMI
     2  2X,5HIESSE ,
     1/11X,11HNREQE(1-10),8X,51X,12HIRCE1 (1-10),8X,4HTSE1,4X,3HIHE/
     3 11X,10HIECE(1-10)   /1H )
      DO 450 I = 1,NEME
      ART(I) = FP5(KK)
      ASDE(I) = FP5(KK + 1)
      DTE(I) = FP5(KK + 2)
      DO 405 J=1,12
      IDES(J)=IP5(MM)
  405  MM=MM+1
      IESSE(I)=IP5(MM)
      DO 410 J =1,10
      MM = MM + 1
  410 NREQE (J,I) = IP5(MM)
      MM=MM+1
      LODME( I)=IP5(MM)
      DO 420 J=1,10
      MM = MM + 1
  420 IRCE (J,I) = IP5(MM)
      MM = MM + 1
      TSE(I) = IP5 (MM)
      DO 425 J=1,10
      MM = MM + 1
  425 IRCE1(J,I) = IP5 (MM)
      TSE1(I) = IP5(MM + 1 )
      IHE(I) = IP5 (MM + 2)
      MM = MM + 3
```

```
      DO 430 J =1,10
      IECE(J,I) = IP5 (MM)
  430 MM = MM + 1
      NDBE(I) = IP5 (MM)
      MM = MM + 1
      KK = KK + 3
      IETYP(I+560)=-1
      ST(I+560)= 0.
      TL(I+560) = 24.0
      TS(I+560)= TSE(I)
      TS1(I+560)= TSE1(I)
      RTU(I+560)=1
      IFOI(I+560)=1
      IEFN(I+560)=0
      NIF(I+560)=1
      IEDC(1,I+560)=0.
      IEDC(2,I+560)=0.
      IEDC(3,I+560)=0.
      IF ( IND(1) .NE. 0 .AND. ITER .LE. 1)
     1WRITE (6,6449) I,IDES,NDBE(I),ART(I),ASDE(I),DTE(I),(IRCE(J,I),J=1
     1 ,10),TSE(I),LODME(I),
     2 IESSE(I),
     3                 (NREQE(J,I),J=1,10),(IRCE1(J,I),J=1,10),TSE1(I),
     4  IHE(I),(IECE(J,I),J=1,10)
 6449 FORMAT(I4,8X,12A6/I6,F5.2,F7.2,F5.2,8X,10F7.0,I3,F8.0,I7/
     110I3,2X,10I7,I2,F8.0/10F6.0)
  450 CONTINUE
  601  IF(ITER.GT.1) GO TO 651
       NFP5=0
      NIP5=0
      READ(5,TYPE)
      IF(IND(1).NE.0 .AND.ITER.LE.1) WRITE(6,9601)
 9601 FORMAT(1H1/50X,15HEVENT TYPE DATA/18H    J     IDENTIFIER,
     1  61X,26H    ADUR     ASD CLASS  NIQR,8X,8HIQR(1-6)  /
     2                               /38H IESS    LODM  KE INT  IH   NREQ
     3(1-10),22X,9HIRC(1-10)/15X,9HIEC(1-10),36X,10HIRC1(1-10))
      NTYPES=NIP5/65
      MM = 1
      KK = 1
      DO 650 I=1,NTYPES
      DO 605 J=1,12
      IDES(J)=IP5(MM)
  605  MM=MM+1
      IESS=IP5(MM)
      MM=MM+1
      ADUR = FP5 (KK)
      ASD = FP5 (KK + 1)
      DO 610 J=1,10
      NREQ(J) = IP5 (MM)
  610 MM = MM + 1
      LODM = IP5 (MM)
      KE = IP5 ( MM + 1)
      INT = IP5 (MM + 2)
      MM = MM + 3
      DO 615 J=1,10
      IRC (J) = IP5 ( MM)
```

```
      IRC1(J) = IP5 (MM + 10)
  615 MM = MM + 1
      IH=IP5(MM+10)
      MM=MM+11
      DO 620 J=1,10
      IEC (J) = IP5 (MM)
  620 MM = MM + 1
      NIQR = IP5 ( MM)
      DO 625 J=1,6
      MM = MM + 1
  625 IQR(J) = IP5 (MM)
      ICLASS = IP5 (MM + 1)
      WRITE(12'I,ERR=9060) ADURIO
      IF(IND(1).NE.0 .AND. ITER.LE.1)
     1 WRITE(6,9650) I,IDES,ADUR,ASD,ICLASS,NIQR,(IQR(J),J=1,6),IESS,
     1 LODM,KE,INT,IH, (NREQ(J),J=1,10), (IRC(J),J=1,10), (IEC(J),J=1,10
     2), (IRC1(J),J=1,10)
 9650 FORMAT(/I4,3X,12A6,   2F7.3,I6 ,I6,6I4/I5,F8.0,2I4,F4.0,10I3,
     1 10F7.0/10F5.0,9X,10I7)
      KK = KK + 2
  650 MM = MM + 2
  651 RETURN
      ENTRY DINPUT
       IF(ITER.EQ.1) GO TO 500
       READ(10) ND,NOSE,(DUMY(I),I=1,11)
  475  NFP3=NOSE*11
      NIP3=NOSE*11
       READ(10) (FP3(I),I=1,NFP3),(IP3(I),I=1,NIP3)
       GO TO 501
  500 NFP3 = 0
      NIP3 = 0
      READ (5,8500)ND,NOSE,(DUMY(I),I = 1,11)
 8500 FORMAT (2I3,11A6)
      READ (5,SCHEVT)
      IF((NFP3.NE.NOSE*11).OR.(NIP3.NE.NOSE*11)) GO TO 9050
       IF(N.LE.1) GO TO 501
       WRITE(10) ND,NOSE,(DUMY(I),I=1,11)
       WRITE(10) (FP3(I),I=1,NFP3),(IP3(I),I=1,NIP3)
  501 KK = 1
      MM = 1
      DO 560 I = 1,NOSE
      IETYP(I)=IP3(KK)
      IPE(I)=IP3(KK+1)
      TS(I)=IP3(KK+2)
      TS1(I)=IP3(KK+3)
      RTU(I)=IP3(KK+4)
      IFOI(I)=IP3(KK+5)
      NIF(I)=IP3(KK+6)
      IEFN(I)=IP3(KK+7   )
      KK=KK+8
      TL(I)=FP3(MM)
      ST(I)=FP3(MM+1)
      MM=MM+2
      DO 510 J = 1,3
      NX(J,I)=IP3(KK)
      PRB(J,I)=FP3(MM)
```

```
      MM=MM + 1
 510  KK = KK+1
      DO 520 J=1,3
      IEDC(J,I)=FP3(MM)
      EDCV(J,I)=FP3(MM+3)
 520  MM = MM + 1
      MM = MM + 3
 560   CONTINUE
      IF(IND(1) .EQ. 0  .OR.  ITER .GT. 1)  GO TO 4999
      WRITE (6,8501)ND,NOSE,(DUMY(I),I = 1,11)
8501  FORMAT (1H1,90X,20HSCHEDULED EVENT DATA/
     14H ND=I3,5X,5HNOSE=I3,4X,11A6//83H  IE  IETYP  TS  TS1  IFOI  NIF
     2  IEFN      NX(1-3)          PRB(1-3)        IPE  RTU  ,5X,8HTL    ST/
      DO 8600 I = 1,NOSE
     3 5X,9HIEDC(1-3),9HEDCV(1-3))
      WRITE(6,8560) I,IETYP(I),TS(I),TS1(I),IFOI(I),NIF(I),IEFN(I),
     1 (NX(J,I),J=1,3),(PRB(J,I),J=1,3),IPE(I),RTU(I),TL(I),ST(I),
     2 (IEDC(J,I),J=1,3),
     2  (EDCV(J,I),J=1,3)
8600   CONTINUE
8560   FORMAT(1H0/1H ,I3,I8,I4,I5,3I6,3I5,3F6.2,2I5,1X,2F6.2,/
     1 1H ,4X,3I3,3F10.3)
4999  CONTINUE
5000  IF (IERR.EQ.0) RETURN
      STOP
9010  IERR = 1
      WRITE (6,9011)
9011  FORMAT (30H1ERROR IN FOLLOWING INPUT LIST/25HPROGRAM WILL NOT CON
     1INUE)
      WRITE (6,PARAM)
      GO TO 200
9020  IERR = 1
      WRITE (6,9011)
      WRITE (6,PERSNL)
      GO TO 300
9030  IERR = 1
      WRITE (6,9011)
      WRITE (6,EQREVT)
      GO TO 400
9040  IERR = 1
      WRITE (6,9011)
      WRITE (6,EMREVT)
      GO TO 601
9050  IERR = 1
      WRITE (6,9011)
       WRITE(6,SCHEVT)
       GO TO 5000
9060   WRITE(6,9012)
9012   FORMAT(20H1D. A. ERROR--QUIT          )
      RETURN
       END
```

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