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A CONCEPT FOR DEVELOPING A DATA BASE TO AID IN SYSTEM MANNING PREDICTION

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for

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This research note presents a concept to aid in the development of systems which can be operated and maintained by available personnel. This concept is predicated upon the development of a data base which can be used to predict the availability of personnel with specific constellations of characteristics at specified levels. The data base and associated methodology are described at the level of component concepts. The purpose of the note is to present an integrated scheme which can be used in investigating the logic of such a concept.

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FOREWORD

The Army's primary need is not hardware or software, but weapons system performance. Hardware and software are means to that performance. In most cases, reaching that performance end requires the operation and maintenance of hardware and software by people. People's capabilities vary, but threat-driven performance requirements do not vary. The variation of people's capabilities affects the achievement of those performance requirements. The ability to determine those capabilities required by hardware and software and predict the availability of personnel with those capabilities raises the probability of the Army achieving its performance requirements.

This paper presents a detailed concept for integrating: front-end-analysis, personnel characteristics and capabilities analysis, personnel availability analysis, training effectiveness analysis, and human factors engineering analysis into a single system for enhancing the probability of achieving performance requirements in the acquisition process. These integrated analyses are used to influence the hardware and software design process, determine the availability of appropriate personnel, and provide alternative means for tapping a larger pool of personnel when necessary. At the conceptual level, it describes the analysis methods, the means and logic for integrating them, and the personnel characteristics data base that would be central to their integration.

The purpose of this paper is to serve as a catalyst for more detailed work and a blueprint for the integration of the products of this work.

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BRIEF

The Army wishes to acquire weapon systems that can be operated and maintained by available soldiers. To do so, three general problems must be alleviated:

1. The problem of influencing the hardware/software design to increase the chances of manning it with potentially available soldiers.

2. The problem of evaluating the hardware/software design to determine if it can be manned by potentially available soldiers, and if not determining the soldier characteristics that produce the manning defit.

3. The problem of determining how to structure (or restructure) training, function allocation, interface design, or performance requirements to access additional soldiers and make manning possible.

This paper consists of a description of an integrated concept for dealing with these problems. It is divided into three sections.

The first section describes a series of analytic methods for aiding in the solution of each of the above problems, the logic upon which these methods are based, and the concept for a characteristics data base which is used to integrate the various analytic methods.

The second section of this paper consists of an amplification and explanation of one of the basic positions of the first section that drove the requirement for a data base at the personnel characteristics level, rather than the Military Occupational Specialty (MOS) level. It provides the detailed arguments and logic that preclude the use of MOS categories as the bases for evaluating the manning potential of hardware and software components of a system.

The third section of this paper consists of a series of hypothetical, detailed steps by which a user would interact with the proposed characteristics data base to perform manning potential analyses. It is in this section that the logic of the integration of the various analysis methods through the characteristics data base can be understood most clearly.

CONTENTS

The Concept

Introduction: The Systems Acquisition Problem

How does an organization acquire a sufficient number of systems that are able to perform at required levels, in an acceptable period of time, for an acceptable cost, without significantly degrading the effectiveness of other systems being acquired? This is the overall problem of system acquisition.

An understanding of this problem necessitates a definition of the term system. Customarily, a system is defined as a collection of hardware and software components that are able to function for some common purpose over a period of time. Unless they are totally automated, collections of hardware and software components alone cannot do so.

For this reason, a system that is operated and maintained by people must include such personnel in its definition. Further, since this personnel component of the system normally cannot function adequately without specialized training, that training must also be considered a component of the system being defined. With this, more inclusive, definition of a system, system acquisition can be seen to include personnel and training acquisition.

Once a system is defined as a series of components that include personnel and training, the systems acquisition problem can be translated as it applies to these components. At this more detailed level of specificity, the acquisition problem can be translated into the following manning problems:

1. How can system designs be influenced so that their hardware/software components can be operated and maintained at acceptable levels by realistically available personnel with realistically available training?

2. How can hardware/software component designs be evaluated to determine:

    a. The types of personnel required to operate and maintain them to the levels required?

    b. The availability of the required numbers of those personnel?

    c. Alterations in system design that would improve personnel availability?

d. Costs of adequate manning?

e. Effects of adequate manning on the effectiveness of other systems being acquired?

To alleviate the manning portion of the systems acquisition problem, a method is required to aid each of its two previously described manning problems.

Influencing Hardware and Software Design-The Predesign Phase

The proposed method for influencing hardware/software design consists of developing detailed system performance requirements and general operational and maintenance personnel descriptions; passing this information to hardware/software designers; and requiring that the resulting design be capable of that performance with those personnel. This information tells the designers:

1. The type of required performance, the conditions under which the performance will take place, the criteria by which successful performance will be determined, and difficulties personnel have had previously with such performance.

2. Significant information about the personnel who will be operating and maintaining the hardware/software.

System Performance Requirements

The development of system performance requirements involves the production of a front-end-analysis that is based on overall system performance, rather than an allocation of functions and tasks among various system components and subcomponents. The purpose of the development of such requirements is to influence a hardware/software design that has not yet been made. Therefore an existing design or prototype cannot be used as the basis of the front-end-analysis that drives the requirements. In addition, allocation of functions/tasks among the hardware, software, and personnel components, prior to the initial design introduces an undesirable constraint on the design process. The designer needs to know the criteria of system performance required and the personnel abilities, constraints, and previous problems that affect those criteria. With this information plus knowledge of the current state of applicable technology, the designer can determine how best to allocate functions and tasks to reach their required performance criteria. Therefore, the front-end-analysis provided should deal only with system performance as a whole. A detailed account of a concept for developing a front-end-analysis prior to system design may be found in A Concept for Developing Human Performance Specifications (Kaplan & Crooks, 1980). The concept presented is based on developing an hierarchical, decomposition model of logically required performance that is driven by mission needs.

Once a system performance front-end-analysis requirement has been developed, its products (performance elements and conditions at various criteria) can be used to identify performance data from functionally similar systems. The performance data that is of interest, in this context, consists of the performance (particularly inadequate performance) of soldiers in functionally similar systems. These performance data will give designers cues as to previous hardware/software solutions that were (and will be) unsuccessful.

Information about Personnel

The primary purpose for developing information about the personnel component of a system is to insure that the hardware/software design will integrate successfully with such personnel into a system capable of the required criteria of performance. When systems are composed of several components that interact, they must be designed or selected so that they fit together. This integration is the most difficult problem in designing any complex system. Human operators and maintainers have a limited range of aptitudes and physical characteristics, and as such may be thought of early in the decision process, as fixed components of a system. When one component of a system is fixed, the designs of other, unfixed, components must take the characteristics of the fixed components into account. Therefore, the characteristics of the fixed components must be known by the designers of the unfixed components. In other words, system designers must know the characteristics of the proposed operators and maintainers.

To influence hardware/software design by making it compatible with the characteristics of appropriate personnel, it is first necessary to identify those personnel. Since the hardware/software design has not yet been developed, at this phase, it is not a problem of identifying personnel characteristics required by such a design, but developing a design that appropriate personnel will be able to operate and maintain.

There are two general procedures for identifying the probable personnel components of a system prior to the design of hardware/software: comparability analysis and availability analysis. Both of these analyses manipulate a proposed human characteristics data base, but they attack the personnel identification problem from opposite positions.

Availability analysis has the same desired ends as comparability analysis--to identify significant personnel characteristics and crew sizes, and to provide for successful interaction with hardware and software. However, the methods of these analyses differ significantly. This difference is the question of which personnel groups should be assigned to a system: that group in an apparently applicable current MOS, or that group that is available, because it was not assigned to other systems. Comparability analysis is based on the first of these alternatives, and availability analysis is based on the second.

Comparability Analysis

In comparability analysis, functionally similar systems are selected as a basis for identifying probable operator populations. Probable maintainer populations are identified by first identifying existing systems that are likely to have generally similar hardware/software components and configurations. Once these probable operator and maintainer populations have been identified and designated (using MOS), their significant characteristics are obtained by using a personnel characteristics data base that can be accessed according to MOS and skill level. Next, the characteristics data base is used to estimate the probable number of personnel with the characteristics mapped from the appropriate MOS who will be available at the time of system fielding. With this information, operations and maintenance crew sizes can be estimated. In effect, once personnel characteristics have been identified, they are held constant and crew size becomes the unknown that is being determined using the data base.

Availability Analysis.

In availability analysis, the general Army population is projected for the period of system fielding. All personnel who have been assigned to other systems are subtracted. A factor that estimates administratively unavailable personnel is subtracted. This factor refers to training, transients, holdovers, and students (TTHS). The remaining population, with their estimated characteristics, constitutes what is available to operate and maintain system hardware/software. The personnel characteristics data base is used to identify the mixes of characteristics of the projected, available population. In effect, total personnel size is held constant, and personnel characteristics are the unknowns that are being identified using the data base.

Evaluating Hardware/Software Designs for Manning

Is is one thing to influence a hardware/software design to make it integrate effectively with personnel characteristics; it is another to evaluate that design to determine how effectively it can be manned. In the evaluation phase, it is necessary to determine the actual personnel and crew size requirements of a hardware/software design to determine:

1. The types of personnel required by hardware/software design;

2. Whether an adequate number of such personnel will be available;

3. Whether the effects of training and/or interface design improvements will permit adequate manning;.

4. To what extent system performance requirements could be lowered to permit adequate manning;

5. The monetary costs of adequately manning the system;

6. The effects of manning the system in question on the manning (and therefore the effectiveness) of other systems being acquired in the same period;

7. The personnel characteristics and/or types of personnel that are likely to be in short supply.

The core of evaluation for manning is the ability to predict the personnel required by hardware/software design and the numbers of such personnel that will be available. There are two general methods for making such predictions. In MOS-based methods, appropriate MOS are selected. The numbers of personnel that will be in these MOS are predicted. In characteristics-based methods, characteristics and their levels required for operation and maintenance are selected. The numbers of personnel with the required mix of characteristics at those levels are predicted.

MOS-Based Design Evaluation for Manning

A Military Occupational Specialty (MOS) is a job category that is defined by a series of required tasks. An MOS may be directed toward a specific piece of hardware, a generic class of hardware, or it may be functional (e.g. infantryman).

To apply an MOS-based design evaluation for manning, first it is necessary to identify the functions and tasks required to operate and maintain the hardware/software designed. These required tasks/functions are matched to collections of equivalent tasks/functions that define existing, potentially applicable MOS. The extent to which the required tasks/functions match the existing tasks/functions indicates the likelihood that the MOS in question is appropriate for the hardware/software design. Appropriate operations and maintenance MOS are selected. Once this is done, the front-end-analysis and hardware/software design are used to determine the size of the operations and maintenance crews. The numbers of personnel available currently are determined for the selected MOS. These numbers are applied to a prediction model for the years of system fielding, and MOS population sizes are estimated. The population sizes of the selected MOS are compared with the numbers required to man the system.

The MOS-based evaluation method is relatively simple to implement, and it probably would be relatively easy to use. However, its adequacy is based on four assumptions:

1. All personnel who are assigned to an MOS are capable of performing its constituent tasks at an acceptable level.

2. The new weapon system requires roughly the same group of tasks as does the MOS, in question, and these tasks are to be performed at the same or lower criteria than the MOS requires currently.

3. The tasks that have been defined for the system and the matching MOS have been described at a measurable level that permits meaningful matching.

4. There are no significantly large numbers of personnel outside the matching MOS who have the appropriate characteristics required for adequate task performance for the system.

For the most part, these four assumptions are questionable (see the second section of this paper for a detailed critique of those assumptions). For this reason, MOS-based evaluation methods can be used for so-called "quick and dirty" estimates, but should not prevent the development of more methodologically sound approaches to hardware/software manning evaluation.

Personnel Characteristics-Based Design Evaluation for Manning

A personnel characteristic is a measurement result that can be used to predict performance. It is possible to predict performance from: measures at the physiological level (size, strength, visual acuity, reaction time, etc.), measures at the aptitude level (spatial relations, abstract reasoning, etc.), and measures at the generalized task level (target acquisition, tracking, inputting data, etc.). The major difference among the various measures is their relationship to training. On the one hand there are characteristics that are relatively enduring and interact with training to predict performance. On the other hand, there are characteristics that, themselves, are altered by training. It would be desirable to have sufficient data to make performance predictions from both sorts of characteristics. However, in the absence of such an ideal situation, it is assumed that characteristics used for prediction will be of the enduring type and will consist of a combination of physiological and aptitude measures.

To apply a characteristics-based design evaluation for manning, it is necessary to determine what characteristics (and their levels) are needed to perform the functions/tasks called out in the System Performance Requirements as implemented by the hardware/software (in the design). In addition, since personnel are components of the system, it is necessary to determine the characteristics and their levels that are needed for the performance of functions/tasks that are performed by personnel without the use of system hardware/software.

Once these required characteristics and levels have been determined, it is necessary to select the required numbers of personnel to operate and maintain system hardware/software as designed. In general, this is done either by requiring the designer to state the maintenance and operations crew size per system, or by an independent process of analyzing design elements according to performance requirements and clustering the resulting soldier and soldier-machine tasks into functions and jobs. Overall soldier populations required are computed by multiplying the operational and maintenance crew sizes by the required number of systems per unit time.

Once the characteristics and levels plus the required numbers of personnel and the years of fielding are known, this information is applied to a predictive characteristics data base. The result is the percentage of the required numbers of soldiers (with the required characteristics) that will be available in the appropriate time period. In addition, if the results yield a deficit in available personnel, the characteristics and levels that produced that deficit are provided.

If the required numbers of soldiers with the required characteristics and levels will not be available, a series of alternative and complementary analyses are developed. In general, the purpose of this level of analysis is to determine whether some action or actions can be taken that will result in being able to use personnel with lower characteristics levels, thus enlarging the potential manning population.

There are four types of analyses to aid in determining whether the manning population can be enlarged:

1. Training Analysis.

2. Interface/Function Allocation Analysis.

3. Performance Requirements Analysis.

4. Effects Analysis.

In the case of the first two types (training and interface analyses), the general procedure takes the form of identifying the deficit-producing characteristics, determining the effects an enhancement (training or interface/allocation) would have on required characteristics levels, and reentering the characteristics data base to determine availability. The third type of analysis would be run if the first two could not eliminate the manning deficit completely. In this case, the original performance criteria are themselves questioned. Such questioning takes the form of generating alternative criteria, selecting the best set of criteria that can be manned (determined by recycling the full manning method), and comparing these criteria with the mission area deficiencies that drove the original performance requirements.

Once the determination of the possibility and requirements for system manning have been made, another level of analysis is performed: Effects Analysis. This analysis predict the effects of manning the system in question on the Army as a whole. There are two types of Effects Analysis:

1. Dollar Cost Analysis;

2. Effects on Manning Other Systems;

Dollar cost analysis consists of estimating the costs of manning the system including training, interface redesign (if any), and acquiring the required number of selected personnel. Effects of manning on other systems consists of keeping a running total of the personnel types who will be assigned to systems being fielded in the time period in question, and determining whether the system in question will use personnel who have been assigned to other systems. The product of such an effects analysis is a description of the conflict (or lack of conflict) among systems for the acquisition of personnel with specified mixes of characteristics and the personnel characteristics that are in short supply.

A Data Base of Personnel Characteristics

Both design influence and evaluation require the use of a data base of personnel characteristics. No such data base exists currently. This section consists of a description of a concept for such a data base.

This data base shall consist of three major components:

1. The MOS-Characteristics Map;

2. The Analysis-Characteristics Map;

3. The Population Predictor.

These three components interact to aid the design influencing and design evaluation procedures.

The MOS-Characteristics Map

This is the component used to enter the characteristics data base when comparability analysis is the technique for influencing a design. It should be remembered that the use of MOS for design evaluation was discouraged in this paper. However, MOS are quite useful for influencing design development. This previously described analysis consists of influencing the hardware/software design process by selecting probable operator/maintainer MOS, determining the characteristics of those populations and feeding them back to designers. These characteristics serve as the design limitations of the soldier components of the system with which hardware/software designs will have to be integrated.

To perform this function, the MOS-Characteristics Map will consist of a listing of Military Occupational Specialities (MOS). Each MOS will access the significant personnel characteristics (at the relevant values or levels) that are associated with it. It is assumed that initially these will be historical in nature. That is, they will be the characteristics and levels that recent MOS personnel have demonstrated. With further development it is expected that a prediction model will be incorporated, so that these characteristics and levels will be based on predictions for specified future time periods.

With this structure, the users of the MOS-Characteristics Map will be able to enter the MOS produced by comparability analysis procedures and receive the personnel characteristics at indicated levels, for those MOS. However, such a Map should have an additional use.

By reversing the flow of the component, users would be able to enter personnel characteristics at specified levels and receive candidate MOS that have such personnel. Such a reversal would aid users to determine appropriate MOS when they had determined the characteristics required to operate/maintain design to the required levels.

The Analysis-Characteristics Map

This is the component used to identify required personnel characteristics and levels of those characteristics from analyses of required performance, hardware/software interface design, and training. This component is used to enter the data base in the evaluation of the hardware/software design for manning.

In general, this component matches classes of tasks as performed under classes of conditions with classes of hardware/software interfaces and maps the result to personnel characteristics. It then matches performance criteria, values of conditions (under which performance tasks place), and values of the hardware/software interface design (lift 50 lbs.) and maps the results to levels of personnel characteristics. Finally, this component contains data on the interactions of characteristic levels and amounts of specified training on the performance of classes of tasks. This information is used to trade-off amounts of training with levels of characteristics to arrive at the most cost-effective characteristics levels required by the hardware/software design to perform at the specified criteria.

Although the primary use of the analysis-characteristics map would be to determine the required personnel characteristics and their levels, it could produce other useful information. The mapping process that is basic to such a component would permit analyses in which all but one of the component parameters are held constant, and that one is predicted. For example, ideally if all parameters except amount of training were held constant, it would be possible to predict the amount of training required to reach a given performance level by personnel with a given value of a given characteristic using a given interface.

The Population Predictor

This is the component used to determine the number of available personnel, with a given mix of characteristics at a given level, in a specified time period. It is used to perform availability analyses in the design influencing phase. In the hardware/software design evaluation phase, this component predicts numbers of personnel based on the output of the Analysis-Characteristics Map.

The Population Predictor may be thought of as a multi-dimensional matrix. Each personnel characteristic is a dimension of that matrix. Each of these dimensions is partitioned into values of the characteristic (Aptitude X: high, medium, low, etc.). Each value of each dimension can be connected to all other values of all other dimensions in the matrix. The connection of the values of dimensions may be thought of as producing a cell in the matrix. Each cell in this conceptual matrix contains: the number of personnel with the defined mix of characteristics' levels (for the time period in question), and the percentage of that number that has been assigned to other systems or is otherwise unavailable for manning the system in question.

To compute the contents of the cells, it will be necessary to have data on the number/percentage of each characteristic level that is expected in the Army population. In addition, each cell will have to access a module that is on the order of a lookup table to determine the degree of dependence of the characteristics. In addition, as this component is used for the manning evaluation of systems, the component will have to store the resulting data so that they can be used to determine numbers of personnel already assigned.

Concept Definition: Conclusions

There are two general ways to provide system hardware/software that can be manned adequately by the types and numbers of personnel that will be available: by influencing the hardware/software design process directly, and by evaluating the output of that design process to determine its effects on manning. Both of these require a data base of personnel characteristics that is organized according to personnel aptitudes and other significant characteristics, and that can map hardware/software design and required performance to those characteristics.

This paper consists of a description of concepts for aiding these systems manning processes through the use of such a data base. The purpose of this paper is to provide an upper level description for such aiding methods and their logic. If the logic of these methods is established, this paper should lead to an understanding of how to design a working system, in detail, and the areas of further research that will be necessary to implement that design.

A Detailed Critique of the Use of MOS in Manning Prediction

In the previous section, the use of MOS for evaluating (rather than influencing) hardware/software design was said to be based upon four assumptions. These assumptions were listed and were said to be questionable. On this basis, the use of MOS for such evaluations was considered undesirable. This section presents the detailed explanation for this position.

A Military Occupational Specialty (MOS) is a job category that is defined by a series of tasks required for its performance. An MOS may be oriented towards a specific piece of hardware/software, a generic class of hardware, or an essentially hardware-independent job (e.g., infantryman). Army enlisted personnel are assigned to MOS based, in part, on their aptitudes, abilities, and physical characteristics. Aptitudes, etc. are deemed appropriate for a given MOS based on their utilities for performing the tasks required by previous or existing weapon systems.

When the acquisition of a new weapon system is being considered, it is necessary to determine whether it can be adequately manned (operated and maintained) by personnel who are obtainable by the Army. A number of methods for making this determination are based on predicting whether there will be an adequate number of personnel in appropriate MOS to man this system. In general, these prediction methods are based on the following assumptions (as previously listed in the first section):

1) All personnel who are assigned to an MOS are capable of performing its constituent tasks at an acceptable level.

2) The new weapon system being considered requires the same combination of tasks at the same or lower performance levels as those required by the MOS to which it is matched.

3) The tasks that have been defined for the weapon system and the MOS have been described at a measurable and therefore understandable level that permits a meaningful matching process.

4) Baseline MOS populations consist of essentially all the personnel in the Army who have the appropriate mix of aptitudes/characteristics required for adequate task performance. That is, for the purpose of prediction, one can assume that the number of people in the baseline MOS is the number of people available to man the weapon system. No other personnel can man it.

If these assumptions were accepted, it would be possible to match an MOS to a developing weapon system and use the baseline data for that MOS to predict system manning according to the following general steps:

1) Identify the tasks required for system performance/maintenance.

2) Identify the tasks that define various, potentially applicable MOS.

3) Match system and MOS tasks, and select the most appropriate MOS for that system by selecting the one with the closest match.

4) Determine the number of personnel required by the system's front-end-analysis and conceptual design to operate and maintain the system.

5) Identify the number of personnel currently available in the MOS that have been matched to the system and project that number for the time period in which the system will be fielded.

6) Based on numbers of personnel required by the system and numbers of personnel to be available in the baseline MOS, predict the level of probable system manning.

It is the position of this paper that the required four assumptions do not always hold, and cannot be demonstrated to be sound as a general rule.

<u>All Personnel in a Given MOS Are Capable of Performing Required Tasks</u>

At the time that personnel were assigned to an MOS, it was unlikely that any method for determining directly the levels of task performance was exercised. It is more likely that various personnel characteristics were tested, and that these characteristics were not linked to task performance. Further, it is unlikely that criteria for adequate task performance were set. Therefore, one could not say with any degree of certainty that at the time of MOS assignment, all personnel so assigned were capable of adequate task performance, or could be trained to such performance levels.

Frequently, personnel in training have not had access to the hardware/software they will be using in operation. In addition, task performance criteria are often fragmentary, non-measurable, or team-based. Therefore, following training one cannot say with any degree of certainty that all personnel in a given MOS are capable of adequate task performance.

After being sent to field assignments, personnel often have not been allowed to exercise their weapon system hardware/software realistically due to expense. Frequently, realistic battlefield conditions have not been present when hardware/software was exercised. Task based criteria have not existed, in many cases, for that performance that was tested.

Finally, a significant percentage of the time, tested performance was less than adequate. Therefore, one can not say with any degree of certainty that all MOS personnel are capable, or able to perform their MOS tasks adequately.

The upshot of these difficulties is that frequently one cannot state that the number of personnel in a baseline MOS adequately describes the number of personnel who could (or can) perform adequately a developing system's matching tasks. This is so because one does not know how many of these baseline MOS personnel could perform these tasks adequately, in the first place.

Tasks Are Defined at a Meaningful Level

The use of MOS data to predict manning requirements necessitates the matching of system tasks with MOS tasks. For such matching to be accurate, the tasks must be:

1) At approximately equivalent behavioral levels.

2) Described at a sufficient level of detail to be able to estimate that their requirements on systems and MOS personnel are similar significantly.

For system and MOS tasks to be at an equivalent behavioral level is not particularly unusual, when such tasks have been produced for the developing system. This is fostered by using MOS task lists from preceding systems to produce the new task lists for the developing system. This approach results in a certain circularity in the logic of matching which tends to bias the process.

However, when system and MOS tasks have been developed independently the level of detail of task descriptions frequently is not adequate for accurate task matching. One test of the adequacy of the level of description is measurability. Normally, if one has to decompose a task into smaller pieces of component behavior to identify its salient features for measurement, it has been defined at too gross a level to permit adequate task matching. When tasks have been defined at such a gross level, it becomes quite difficult to determine whether apparently matching tasks actually make similar demands on personnel. An example of such task definition is "Drive Tank". Two such tasks can be matched easily. However, it has been described at such a gross level that the behavior to be measured is a series of invisible components. It is possible that the developing system's behavioral components (read instruments, navigate, start, turn, etc.) may create different demands on personnel than those of the MOS. Therefore, it is possible to match MOS and system tasks, but frequently the tasks have not been developed at a level that is adequate for making this judgement.

New Weapon System has Same Tasks to be Performed at Same or Lower Level

Assuming that matching system tasks have matching or lower performance levels (meaning that the same personnel could perform these tasks0 may produce logical problems.

Without knowing what both the MOS and the developing system's task performance criteria are, one cannot make this judgement. Frequently, neither of these sets of criteria have been developed. If they have been developed, or if such formal, performance level comparison is avoided, it will be the case that some, or all, of the developing system's unwritten criteria are higher than those of the baseline MOS. Finally, even if such criteria have been developed, a conceptual problem in the realm of the meaning of this relationship exists.

All other things being equal, if the levels of performance criteria for the developing system are the same or lower than those of the baseline system, and if the baseline MOS population could adequately perform the tasks in question, then they should be able to perform the developing system's tasks. However, all other things are not always equal.

If the hardware/software has changed, or if the conditions/variables under which performance task place have changed, or if the functional allocation has changed, lower performance criteria may be harder to achieve than higher criteria. Therefore, the direct comparison of performance level criteria is not fully meaningful for manning prediction. Rather, it is necessary to examine personnel characteristics and to establish their required levels based on performance criteria, hardware/software design and conditions/variables.

Baseline MOS Contains All Personnel with Appropriate Capabilities

To use baseline MOS population data to predict the manning of a developing weapon system, one assumes that the MOS in question will supply the required personnel. This assumption is, in turn, based on the assumption that by matching system tasks with MOS tasks, one can identify the appropriate MOS and therefore the appropriate set of population statistics for manning predictions. It may be true that the complete set of tasks, required by a developing system, can only be matched to one MOS. However, different tasks may require the same personnel characteristics.

Therefore, it is probable that personnel who, in the past, would have been assigned to nonmatching MOS have that mix of characteristics that is required to man the developing system. This means that a method that matches system tasks to MOS tasks, selects an appropriate MOS, and bases its manning predictions on that MOS population data is likely to exclude a significant number of personnel who would be capable of manning the system.

Conclusion of the Use of MOS for Manning Prediction in the Design Evaluation Phase

Predicting the operator and maintainer MOS of a developing weapon system is an exercise that has considerable value in the predesign phase. However, using such MOS predictions to identify population numbers, in the evaluation phase, requires the acceptance and viability of a number of questionable assumptions. To the extent that these assumptions are not founded, significantly inaccurate manning prediction will take place in the evaluation phase. The major alternative to basing predictions on MOS populations is to determine the personnel characteristics required by a given design, and base predictions upon the Army-wide population.

Interacting with the Data Base to Alleviate Manning Problems

This section consists of specific steps by which users might interact with the proposed characteristics data base to perform the manning analyses described in the first section of this paper. Clearly, these steps are hypothetical, but they are given here to provide the reader with a more specific idea of the characteristics data base concept that is central to this paper.

Steps for Carrying out Comparability Analysis to Influence Designs

1) Using the front-end-analysis, identify the most similar system from a functional/operational point of view.

2) Using an estimate of probable classes of system hardware/software plus the front-end-analysis, identify the most similar system/components/subcomponents from a maintenance point of view.

3) Using the information from steps 1 and 2 , identify the most probable operations and maintenance MOS populations for the system in question.

4) Access the characteristics data base through the MOS-Characteristics Map by identifying the appropriate MOS time period of fielding.

5) If a given personnel characteristic is represented (in this MOS population) by more than one value, decide whether to describe that characteristic by a range incorporating these values, or by the worst-case value. When this decision has been made for all personnel characteristics accessed by the MOS-Characteristics Map, the description of required characteristics per MOS is complete. The remaining steps (6-16) describe the determination of crew size constraints.

6) For the time period in which the system is predicted to be fielded, estimate the year(s) in which the largest number of systems will be in use concurrently.

7) For the year(s) selected, enter the Population Predictor component of the data base. Identify the sets of cells that describe the values of the characteristics for the MOS identified. In each such cell, determine the number of personnel available without constraint.

8) In each identified cell, determine the number of personnel already assigned to other systems to be fielded concurrently.

9) In each identified cell, determine the number of personnel who must be left unassigned for various administrative reasons (travel, training, transit, etc.). This number is the TTHS factor.

10) Subtract the concurrently assigned and TTHS personnel from the unconstrained number available, in each identified cell.

11) If the comparable system required more than one MOS, repeat steps 4-10 until the number of available personnel (with the required sets of characteristics at the required levels) have been determined.

12) Using the previously prepared front-end-analysis and the original threat analysis, determine the number of systems that would have to exist at one time in the year(s) identified in step 6.

13) For operations and various levels of maintenance, divide the number of available personnel (from step 11) by the number of required systems (from step 12). The resulting numbers are the maximum crew sizes possible per system.

14) Once maximum available crew size has been determined, it can be used directly or as the basis for a more detailed crew size analysis. Such a detailed crew size analysis requires a set of decisions that are independent of the characteristics data base. An example of such decisions is given in steps 15 and 16.

15) One will know if the maximum available crew size is too high by making the following classes of decisions:

a) Does a crew of this size allow for the demonstration of a technical/tactical concept that was a key reason for the development of this system?

b) If the system had a crew of this size, would it be desirable from the point of view of overall system performance? Consider the required system size/visibility, weight/mobility.

c) Does the probable workload of operating/maintaining such a system necessitate such a crew size?

d) Is the expense of acquiring, training, retaining, etc. a crew of this size a realistic amount for this system (considering its criticality to the Army)?

By working downward from the maximum available crew size and repeating these decisions, it should be possible to estimate an available and acceptable crew size.

16) One will know if the maximum available crew size is too low to be acceptable by making the following classes of decisions;

a) Is this crew size significantly smaller than that for similar functions in a comparable system?

b) If the answer to "a" is NO, is there evidence that such an equivalent crew was able to perform its functions adequately?

c) Does the current level of technology permit a crew of this size composed of the population in question to fulfill its required functions, or will the workload be too high?

If the result of these decisions is that the maximum available crew size is unacceptably low, the following alternatives should be considered:

- Reducing the number of systems required.
- Gaining access to other MOS.
- Gaining access to personnel who were assigned to other systems.
- Checking the workload capability estimate.
- Cancelling the procurement.

Steps for Carrying out Availability Analysis to Influence Designs

In general, Availability Analysis differs from the previously described Comparability Analysis as follows. Comparability Analysis identifies crew size (which is treated as a variable) by holding personnel characteristics constant. Availability Analysis identifies personnel characteristics (which are treated as variables) by holding crew size/required personnel constant.

1) Based on the front-end-analysis and needs statement, determine the number of systems required at one time in the year(s) of highest demand.

2) Determine probable operational and maintenance crew sizes by:

   a) Comparability Analysis.

   b) Setting an arbitrary crew size, and considering that size using the decision questions in the previous section (step 15), working down to an acceptable size.

3) Estimate the required population sizes by multiplying the output of step 1 by that of step 2.

4) Enter the Population Predictor component of the data base, and identify the cell(s) in which an adequate number of personnel will be available to meet the personnel requirements in the year(s) determined. When looking for an adequate number of personnel, the data base must be manipulated so that the resulting numbers represent personnel with values of characteristics up to and including those represented in the identified cell(s). That is, the data base is being used to identify personnel characteristics as constraints on design. In this case, it is the upper bounds of a population's characteristics' values that defines these constraints.

5) If step 4 resulted in the identification of more than one cell (with its mix of characteristics' values and resulting population size) per operation or maintenance crew, these alternative sets of characteristics and values will have to be reconciled. The following methods for this reconciliation (and resulting selection) should be considered:

   a) List the various sets of characteristics and values as alternatives, and let system designers select the population characteristics and values for which the hardware/software design is to be made.

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b) Select the cell with the largest number of available personnel on the ground that the probability will be enhanced of actually obtaining sufficient numbers of personnel.

c) Match the personnel characteristics' values to the probable hardware/software requirements and select the closest match. The method for determining the probable hardware/software requirements prior to the development of a design is problematic at best. However, it might be approached by:

- o Predicting the probable technology to be used in the design.
- o Relating this technology that in similar systems and the experimental literature.
- o Identifying the personnel characteristics that constrained performance in these systems/experiments.
- o Matching these characteristics to the alternative sets and selecting the set that is most likely to avoid these problems/constraints.
- o Select the cell with the worst-case set of characteristics' values on the ground that if the system hardware/software is designed for this worst-cast, available population, all other alternative populations will be able to use it.

6) Repeat steps 4 and 5 for each major crew type (operational and maintenance by maintenance level).

7) If no cell contains an adequate number of personnel (as compared with the required number for the crew in question), the following alternatives should be considered:

- o Reducing the number of systems required.
- o Reducing the crew size required.
- o Gaining access to personnel who were assigned to other systems on the ground of higher criticality for the system in question.
- o Cancelling the procurement.

<u>Steps for Carrying out Personnel Characteristics-Based Design Evaluation</u>

1) Enter the Analysis-Characteristics Map component with required information from the hardware/software design and the system front-end-analysis. Using this component, determine the characteristics and their levels or values required to perform the required tasks at the required criteria in the required conditions with the applicable hardware/software. This initial determination is made based on data for entering Army personnel. That is, the initial

characteristics and levels are those required for acceptable performance (using the hardware/software) without additional Army training.

2) Using either direct information from the hardware/software design or clustering/job analysis techniques (on the design and front-end-analysis), determine the crew size(s) required (operational and maintenance).

3) Using the needs analysis, threat analysis, and front-end-analysis, determine the number of systems required at any one time for the period of greatest system use.

4) Using the information from steps 2 and 3, determine the number of personnel required (per job and crew type) for the period of greatest system use.

5) Link the characteristics and levels generated in step 1 to the crews and job types generated in step 4.

6) Enter the Population Predictor component of the data base with the characteristics and levels generated for the period of time identified as being that which will most greatly stress manning. Using the Population Predictor estimate the percentage of the required numbers of personnel with the required mix of characteristics (at required levels) that will be available. It should be remembered that the characteristics levels are those required to reach criteria without additional Army training.

7) If significantly less than 100% of the required personnel will not be available, the Population Predictor lists the deficit producing personnel characteristics and levels. These deficit producing characteristics are divided into the categories of physiologic and aptitude.

8) Deficit characteristics are introduced into the Analysis-Characteristics Map (which has stored the initial mapping procedure), and mapped back into their originating tasks/conditions/criteria/design elements.

9) These elements that are mapped from deficit physiologic characteristics are routed to appropriate organizations for a Human Factors Engineering analysis and conceptual redesign.

10) Those elements that are mapped from deficit aptitude characteristics are routed to appropriate organizations for a training analysis and a determination or probable type(s) and amount(s) of training to be given by the Army.

11) The conceptual Human Factors Engineering redesign and training data are introduced into the Analysis-Characteristics Map, and the new, required personnel characteristics and levels are output.

12) These characteristics and levels are introduced into the Population Predict or (along with the previously obtained characteristics and levels) to determine the availability of personnel.

13) If there are still deficit producing characteristics, as a result of step 12, these are again categorized as physiologic or aptitude types.

14) The aptitude, deficit characteristics are introduced into the Analysis-Characteristics Map and their originating elements (see step 8) are routed to an appropriate organization for a Human Factors analysis leading to function reallocation and/or interface simplification.

15) The physiologic, deficit characteristics are introduced into the Analysis-Characteristics Map and their originating elements are routed to an ongoing workbasket of potential design/front-end-analysis flaws.

16) The Human Factors interface simplification/function reallocation is introduced into the Analysis-Characteristics Map, and the new required personnel characteristics and levels are output.

17) These characteristics and levels are introduced into the Population Predictor (along with the previously obtained characteristics and levels) to determine the availability of personnel.

18) If there are still deficit producing characteristics (which are by definition aptitudes), they are introduced into the Analysis-Characteristics Map the their originating elements are routed to an appropriate organization for an additional training analysis. The purpose of this analysis is to determine whether there are other, less probable, training methods and/or amounts that might further lower the required aptitude level(s), thus increasing the potential manning population.

19) If the analysis results in no reasonable change in training, this information is entered in the Analysis-Characteristics Map along with the originating elements. These elements and their deficit characteristics and levels are then stored in the ongoing workbasket of potential design/front-end-analysis flaws (see step 15).

20) If the analysis results in a change in training, the elements of this training play (type and amount of time) are entered into the Analysis-Characteristics Map, and the new, required characteristics and levels are output.

21) These characteristics and levels are input to the Population Predictor (along with previously obtained characteristics and levels) to determine the availability of personnel.

22) If there are still deficit producing characteristics, they are introduced into the Analysis-Characteristics Map and those performance criteria and conditions that are originating elements are output.

23) These criteria and conditions are routed to an appropriate organization to determine if they can be reduced/eliminated and still meet the requirements of the original threat analysis/needs statement.

24) If the analysis results in no changes to criteria or conditions, this information is entered in the Analysis-Characteristics Map along with the originating elements. These elements and their deficit characteristics and levels are stored in the ongoing workbasket of potential design/front-end-analysis flaws.

25) If the analysis results in changes to criteria and/or conditions, these changes are entered into the Analysis-Characteristics Map, and the new characteristics and levels are output.

26) These characteristics and levels (along with the previously obtained characteristics and levels) are input to the Population Predictor to determine the availability of personnel.

27) If there are still deficit producing characteristics, they plus their originating elements are added to the ongoing workbasket of potential design/front-end-analysis flaws.

28) If there are no deficit producing characteristics (a situation that could occur as a result of a number of steps starting at step 6), the system hardware/software design is potentially mannable by personnel who will be available to the Army. However, to this point the issue of the effects of the manning of other systems on the manning of this system and the reverse have not been dealt with.

29) Access those cells in the Population Predictor that describe your crew population. Call up the data that states the percentage of that population which has already been assigned elsewhere for the period in question.

30) If (after carrying out step 29) an adequate number of appropriate personnel remain to form the crew in question, there are no significant interference effects between the manning of this system and the manning of other systems. However, if an adequate number of appropriate personnel does not remain, an effects analysis must be performed.

Steps for Carrying out Personnel Characteristics-Based Effects Analysis

In the first section of this paper, three types of effects analysis are described: effects of manning on other system, dollar cost effects, and strategic effects. All three of these analyses are important, but the personnel characteristics data base (being described) deals only with the first type of analysis. The latter two types of effects analysis are beyond the scope of this paper. The general steps for manning effects analysis are as follows.

1) From the front-end-analyses of the systems that are competing for personnel, determine the relative criticalities of their missions and, therefore, of each system as a whole.

2) There are three methods for handling the problem of systems competing for personnel (if personnel pool cannot be enlarged, generally):

   a) Produce fewer of one or more of the competing systems.

   b) Use personnel of less adequate characteristics for manning one or more of the systems.

   c) Do not procure one or more of the competing systems.

   The first and third methods can be investigated by comparing the relative criticalities of the competitive systems (as a simple expedient), and by trying out the effects of reduction or cancellation in combat models (as a more complex expedient). The second method can be investigated by predicting performance of the various, competitive systems in the hands of personnel or specified, less adequate characteristics. Such prediction is done by:

a) Entering the Analysis-Characteristics Map.

b) Holding the characteristics and their levels constant, rather than allowing them to vary.

c) Holding training type and amount constant.

d) Taking the resulting performance level(s) that are output (soldier performance) and determining its effects on system performance by either analytical means via the hierarchical front-end-analysis; or through introducing it into an appropriately formatted combat model.

Conclusion

This section consists of hypothetical steps for interacting with a conceptual personnel characteristics data base to aid in the general processes of influencing system hardware/software designs to enhance their integrating with available personnel and evaluating those designs to determine whether they can be effectively manned and what to do to enhance manning. These steps should be viewed as a preliminary functional specification that makes this conceptual aiding system more concrete and therefore more understandable. It is hoped that by making this concept as concrete as possible the result will be serious consideration by interested readers and positive criticism that will lead to improvement in the underlying ideas. Clearly, what is being described here will not come about quickly or easily. However, all useful products start as ideas. The integration of such ideas and their unambiguous communication are required if they are to become the basis of a new reality.