Research Product 90-30

Incorporating Operator Workload Issues and Concerns into the System Acquisition Process: A Pamphlet for Army Managers

September 1990

Fort Bliss Field Unit
Systems Research Laboratory

U.S. Army Research Institute for the Behavioral and Social Sciences

U.S. ARMY RESEARCH INSTITUTE
FOR THE BEHAVIORAL AND SOCIAL SCIENCES

A Field Operating Agency Under the Jurisdiction
of the Deputy Chief of Staff for Personnel

EDGAR M. JOHNSON
Technical Director

JON W. BLADES
COL, IN
Commanding

Research accomplished under contract for
the Department of the Army

Analytics, Inc.

Technical review by

Dennis D. Collins
Donald C. Crissup
Jon J. Fallesen
Ronald L. Fischer
Gordon J. Goodwin
Glenn Hewitt
Gerald A. Klopp
Martin Krievs
Rudolph L. Laine
Lee A. Lewis
Linda A. Pierce
Bernard Schuster
Gregory E. Tarver

NOTICES

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS --
2a. SECURITY CLASSIFICATION AUTHORITY -- 2b. DECLASSIFICATION/DOWNGRADING SCHEDULE --	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.
4. PERFORMING ORGANIZATION REPORT NUMBER(S) Analytics Technical Report 2075-56	5. MONITORING ORGANIZATION REPORT NUMBER(S) ARI Research Report 90-30
6a. NAME OF PERFORMING ORGANIZATION Analytics, Inc. 6b. OFFICE SYMBOL (If applicable) --	7a. NAME OF MONITORING ORGANIZATION U.S. Army Research Institute Field Unit at Fort Bliss, TX
6c. ADDRESS (City, State, and ZIP Code) 2500 Maryland Road Willow Grove, PA 19090	7b. ADDRESS (City, State, and ZIP Code) P.O. Box 6057 Fort Bliss, TX 79906-0057
8a. NAME OF FUNDING/SPONSORING ORGANIZATION U.S. Army Research Institute for the Behavioral and Social Sciences 8b. OFFICE SYMBOL (If applicable) PERI-S	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER MOA903-86-C-0384
8c. ADDRESS (City, State, and ZIP Code) 5001 Eisenhower Avenue Alexandria, VA 22333-5600	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. 62785A; PROJECT NO. 790; TASK NO. 1102(113); WORK UNIT ACCESSION NO. C1

11. TITLE (Include Security Classification)
Incorporating Operator Workload Issues and Concerns into the System Acquisition Process: A Pamphlet for Army Managers

12. PERSONAL AUTHOR(S)
Christ, Richard E. (ARI); Bulger, John P.; Hill, Susan G.; Zaklad, Allen L. (Analytics)

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Interim	FROM 86/09 TO 90/01	1990, September	

16. SUPPLEMENTARY NOTATION Contracting Officer's Representative, Richard E. Christ. Other authors currently at the following new locations: J. P. Bulger at Science Applications International Corp.; S. G. Hill at Idaho National Engineering Laboratory; A. L. Zaklad at CHI Systems, Inc.

17. COSATI CODES

FIELD	GROUP	SUB-GROUP
23	02	
05	08	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Workload; Operator system interface; Requirements; MANPRINT; Systems management; Measurement; Human performance

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This pamphlet defines and discusses the concept of workload as it relates to modern "high technology" systems. It also identifies Department of Defense and Department of the Army policy, regulations, and responsibilities for ensuring that operator workload (OWL) issues and concerns are incorporated in the Army materiel acquisition process and offers suggestions on what management-level decision makers should know to adequately address OWL at each stage of the acquisition process.

After defining OWL as the relative capacity to perform, the authors take the position that limited performance capabilities of the human component of a system must influence the requirements and design of a system in much the same way as do limited capabilities of materiel components. If OWL is not considered early and continuously during the design, development, and evaluation of a system, the Army will not know if the system makes excessive demands on the operator until it is too late for a cost-effective solution.

(Continued)

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Richard E. Christ	22b. TELEPHONE (Include Area Code) (915) 568-4491; 22c. OFFICE SYMBOL PERI-SB

DD Form 1473, JUN 86 Previous editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

ARI Research Report 90-30

19. ABSTRACT (Continued)

The guidance provided in this report is based on the relationship between OWL and the Army manpower and personnel integration (MANPRINT) initiative and on the key role of the system MANPRINT management plan (SMMP) and the MANPRINT joint working group (MJWG) in addressing and tracking OWL issues and concerns throughout the acquisition process. This guidance promotes efforts to ensure total system effectiveness by continuous integration of all information relevant to soldier performance and reliability into the system development process.

Keywords: operator system interface, systems management. (KR)

Research Product 90-30

Incorporating Operator Workload Issues and Concerns Into the System Acquisition Process: A Pamphlet for Army Managers

Richard E. Christ
U.S. Army Research Institute

John P. Bulger, Susan G. Hill, and Allen L. Zaklad
Analytics, Inc.

Field Unit at Fort Bliss, Texas
Michael H. Strub, Chief

Systems Research Laboratory
Robin L. Keesee, Director

U.S. Army Research Institute for the Behavioral and Social Sciences
5001 Eisenhower Avenue, Alexandria, Virginia 22333-5600

Office, Deputy Chief of Staff for Personnel
Department of the Army

September 1990

Army Project Number
2Q162785A790

Human Performance Effectiveness and Simulation

FOREWORD

The Systems Research Laboratory of the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) supports the Army with research and development on manpower, personnel, training, and human performance issues as they affect the development, acquisition, and operational performance of Army systems and the combat readiness and effectiveness of Army units. Concerns that underlie all of these issues are the mental workload imposed on and experienced by the operators of newly emerging, high-technology systems, and the impact of that workload on operator and system performance. The Fort Bliss Field Unit is conducting exploratory development research to establish an operator workload (OWL) assessment program for the Army.

This research product is the first step in the OWL assessment program. It was produced to alert and orient Army management-level decision makers to the need and the procedures for incorporating operator workload issues and concerns into the system acquisition process. It justifies the necessity for OWL in systems acquisition by (a) reviewing conceptual issues important to workload, to include defining OWL, describing the relationship between OWL and system performance, and discussing factors that affect the form of that relationship; and (b) reviewing regulatory documents that mandate that OWL issues and concerns be addressed in the system acquisition process.

The report presents and discusses three actions that must be taken to permit OWL issues and concerns to influence system design and development. These actions will develop and implement plans that (a) define OWL issues and concerns, (b) assess OWL, and (c) integrate OWL into the system acquisition process. It is recommended that the Army initiative for manpower and personnel integration (MANPRINT) be the vehicle for integrating OWL considerations into the acquisition program. Operator workload issues are related to the six MANPRINT domains, and the mechanism for integrating OWL-related activities into the system acquisition program exists in the system MANPRINT management plan (SMMP).

EDGAR M. JOHNSON
Technical Director

ACKNOWLEDGMENTS

Preparation of this research product benefited immeasurably from the assistance provided by many individuals. First and foremost, special thanks is given to those listed as technical reviewers on the inside front cover of this pamphlet. Each took time out from their already "overloaded" schedules to review and offer comments on earlier versions of this report. They helped the authors tighten up the discussion of workload concepts and incorporate into the pamphlet a greater number of more illustrative examples of workload issues and their implications for system acquisition programs. Special recognition in this regard is extended to Jon Fallesen, Gordon Goodwin, Gerald Knopp, Linda Pierce, and Bernard Schuster. Donald Crissup, Ronald Fischer, Martin Krievs, Lee Lewis, and Gregory Tarver helped us recognize the importance of operator workload issues for force development and logistic supportability. Dennis Collins, Glen Hewitt, and Rudy Laine provided specific input on the target audience of this pamphlet and much encouragement.

Thanks are extended to Harold Booher and Bruce Braun of the Directorate for MANPRINT in the Office of the Deputy Chief of Staff for Personnel at Headquarters, Department of the Army, and to Ray Brandenburg of the MANPRINT Programs Division of the U.S. Army Personnel Integration Command. These individuals have contributed general and continuous guidance, inspiration, and support to this specific product, as well as to the overall ARI operator workload research program.

Finally, the authors acknowledge the contribution of other members of the original operator workload (OWL) team, including Regina M. Harris, Helene P. Iavecchia, Alvah C. Bittner, Jr., A. O. Dick, Robert J. Lysaght, Paul M. Linton, James C. Byers, and Brian D. Plamondon. Each participated in activities that provided the knowledge and experiences necessary for preparing this research product. Each also contributed thoughts on the form and substance of the research product.

INCORPORATING OPERATOR WORKLOAD ISSUES AND CONCERNS INTO THE SYSTEM ACQUISITION PROCESS: A PAMPHLET FOR ARMY MANAGERS

CONTENTS

LIST OF FIGURES

CONTENTS (Continued)

INCORPORATING OPERATOR WORKLOAD ISSUES AND CONCERNS INTO THE SYSTEM ACQUISITION PROCESS: A PAMPHLET FOR ARMY MANAGERS

CHAPTER 1. INTRODUCTION

Purpose

The purpose of this pamphlet is to provide to management-level decision makers information needed to incorporate operator workload (OWL) issues and concerns into the Army materiel acquisition process (MAP). The pamphlet defines and discusses the concept of workload as it relates to modern "high technology" systems, identifies Department of Defense and Department of Army policy, regulations, and responsibilities for ensuring that OWL issues and concerns are incorporated into the MAP, and offers suggestions on what the manager ought to know to adequately address OWL at each stage of the acquisition process.

The target audience of this pamphlet is Army managers, military or civilian, involved in any stage or activity inherent in the MAP, to include the conceptualization, design, development, procurement, manufacture, improvement, test and evaluation, or fielding and deployment of Army systems. It has been written with the assumption that the reader is not a behavioral scientist, nor a human factors practitioner.

This pamphlet is not a listing of activities and procedures whose step-by-step implementation would identify and then eliminate OWL issues and concerns during the MAP. Uncertainties associated with the definition and measurement of OWL and its relationship to system effectiveness preclude such a simplistic approach. Rather, the pamphlet highlights the fact that consideration of OWL during the MAP will lead to more effective systems and suggests strategies for implementing these considerations. In this way, the pamphlet promotes efforts to ensure total system effectiveness by continuous integration into the MAP of all information relevant to soldier performance and reliability.

Background

The Army's ongoing modernization program schedules the introduction of some 400 new materiel items to the field; many of them will be weapon and support equipment that rely on increasingly advanced technology. While government and industry science and technology programs have produced some truly impressive materiel systems, there are concerns that many may be too technologically complex for soldiers to operate and maintain. The assertion is often made that the pull of high technology dominates system development at the expense of consideration of the impact on the soldier.

As new technologies are developed and incorporated into new systems, their effects on the human operator need to be identified and evaluated. For example, the newest generation of advanced military systems often incorporates computers used for multifunction displays, decision aiding, or computational-assisted control. These technological changes have resulted in changes in operational procedures and in the functions of the operators of the systems. In general, operators are moving to supervisory, monitoring, and overseeing functions -- in many instances computers are doing the work and the operators are continually checking for failure or emergency conditions. It seems fair to characterize the changes in the functions and tasks of the operator as becoming more mental, more cognitive in nature. Even so, some things have not changed; operators are still often required to perform their functions in psychologically stressful and physically demanding environments.

A plausible scenario could have an operator sitting in front of one or more computer displays. The displays contain information which must be read, understood, and acted upon. Several potential targets are displayed and the operator must decide which, if any, should be engaged. In this scenario, the operator is one of a crew that is expected to perform both night and day, even when fatigued. Some functions may be able to be shared among crewmembers, others may not. The amount and rate of information being displayed is high; communications channels are open and busy; decisions must be made and acted upon within seconds. The operator and crew may not be able to perform the required tasks within the critical time window. The generic scenario played out for this situation may result in operator overload and mission failure.

The Problem

This pamphlet is concerned with one aspect of the scenario just described: The workload imposed upon and experienced by the operator or crew of the system. If operator workload is not considered early and continuously during the design, development, and evaluation of a system, the Army will not know if the system makes excessive demands on the operator until it is too late for a cost effective solution.

For this pamphlet, operator workload is mainly concerned with the mental effort expended by the operator. Workload can be thought of as the personal "cost" of accomplishing a goal or mission. Another way of considering workload is as the relative capacity to perform. This latter conception encompasses the idea that operators have limits in their capability for accomplishing goals.

The key issues are: (a) how might human operator capacities and limitations constrain system performance and (b) how should limits in an operator's capacity to perform affect the design of a system within which the human must operate? If workload imposed upon or experienced by an operator is excessive, the operator may exceed his or her capacity to respond and fail to perform required tasks adequately. After OWL has been measured, and potential workload problems identified, then attempts can be made to alleviate these problems through improved design of the operator-system interface, changes in training strategy, appropriate personnel selection activities, or some other remedial action.

This pamphlet is not intended to be a literature review. The reader desiring more detailed technical information is referred to the publications listed in the References section, particularly the comprehensive literature review recently published by the Army Research Institute (Technical Report No. 851).

Overview

The organization of this document is as follows. Chapter 2 -- "The concept of workload" -- reviews and discusses the conceptual issues important to workload. Concrete examples are given, a definition of workload is proposed, and the relationship between workload and performance is discussed. Next, Chapter 3 provides a brief review of the important Army documents which mandate that OWL issues and concerns be addressed in the system acquisition process. Finally, Chapter 4 outlines three necessary steps that Army managers must take to effectively deal with OWL: (a) define OWL issues and concerns, (b) assess OWL, and (c) integrate OWL issues and concerns into the system acquisition process.

The three chapters that follow may be treated as separate articles. Hence, if the reader has no need to review OWL-related conceptual issues or the requirements and responsibilities for addressing OWL during the MAP, Chapters 2 or 3, respectively, may be skipped. The contents of Chapter 4, however, address the primary purpose of this pamphlet: To alert and orient the managers of Army acquisition programs to procedures for incorporating operator workload issues and concerns into the system acquisition process.

CHAPTER 2. THE CONCEPT OF WORKLOAD

What Is Workload?

An Example: Driving a Vehicle

As an illustration of what is meant by the term workload, imagine you are driving your favorite car. As you go through this mental exercise, we will progressively increase the difficulty of the car driving task in a number of different ways. Additionally, we will use some words like stress and effort in a colloquial manner. When you are through with the exercise you may not know exactly what workload is, but you will have a feel for how operator workload (OWL) can vary for a task as common as driving a car. And more importantly, you will have a feel for the importance of workload and the various factors that affect workload. One point we wish to make in this example is that workload is not the same as performance.

- Since you are an important person, the State Police have closed the Interstate to all other drivers. You are cruising down the highway at the speed limit on a nice, sunny day. Easy driving, right?
- You have just passed the state line. This second state doesn't think you are quite as important and now you have some traffic. Still not bad.
- You have been driving for a while, it is approaching the rush hour near a metropolitan area and traffic is picking up.
- It is Friday afternoon and every one wants to get home or out of town before the storm hits. Traffic is now much heavier than normal and slowing down.
- You left early this morning and didn't realize you hadn't stopped for lunch. You're tired and hungry.
- Traffic is now reduced to a crawl. You also forgot to get gas when you forgot lunch. You've got to get to an exit and find a gas station.
- While you are crawling along, the weather has turned. It is now raining.
- It has also gotten dark and visibility is not good. The highway is not well marked and you must be careful not to miss your turnoff.

- Worse, the car in front does not have brake lights so you have to pay very close attention to this stop-and-go stuff. Eyes on car in front.
- A few miles are covered, but with the dark, the outside temperature has also dropped. It is no longer just raining, it is freezing. Several cars are off the road. Still bumper to bumper and gas is getting very low.
- Your two year old, who was sleeping in the backseat, wakes up. He is hungry, scared, and crying.
- It's not a lot of fun with all that is going on. In addition, the engine sounds like it is missing and you know you are not yet quite out of gas. (You've turned the radio down and would like to turn the kid down.)

You are about to "lose it" as anyone who has been in a similar situation can attest. And note, we didn't cheat by giving you an unfamiliar vehicle with manual shift instead of automatic, or even an English car with the wheel on the "wrong side." We assumed that your prior training and experience were in effect. Further, we didn't have hostiles shooting at you. Nor did we have you crash -- Performance remained acceptable, despite increasing workload. This was possible because as the demands associated with the driving task increased, you, the driver, varied your approach to the driving task and its context, and you probably exerted more effort.

A Second Example: Mental Load

Before we start discussing workload in a formal way, we want to consider one more example, this time strictly mental load. First, we are going to ask you to do a couple of tasks that are highly overlearned and very easy. Then we will do the tasks again, but in a combined manner. Not only does the demonstration illustrate an example of cognitive workload, it illustrates an important point about measuring workload: Two easy tasks added together can sometimes result in a very difficult task. Not an easy situation to predict. As you do the tasks, take your time. You might even want to time yourself on each of the parts.

- Recite the alphabet,
- Count from 1 to 26,
- Now do both, interleaving the alphabet with the counting, A-1, B-2, etc., saying the answers.

If you actually got all the way through the combined task, you are unusual. Most people give up about G-7 or H-8. Why is it so difficult? Let us use this example to diagnose the basis of the difficulty and illustrate workload analysis. Get out a pencil and a piece of paper. Do the double task again, this time writing down the answers. Any difficulty in getting all the way through this time? Part of the difference between the two is that the pencil and paper reduces the heavy burden on memory. There are some additional reasons, but the point is that the same task can be difficult or relatively easy depending on how we do it. And often we can identify the reasons for the differences. For this example there is usually a performance failure for the task in which memory is burdened, no matter how much effort you exert, while performance is acceptable when the task involves the use of pencil and paper, usually with only minimal effort.

These two examples should give you an idea about factors that affect workload, and factors that affect the relationship between how an operator responds to a difficult task and how well the operator performs the task. The remainder of this chapter will build on these ideas. First, we will elaborate on the relationship between workload and performance. Then, we will discuss in more detail factors that affect workload and performance. Finally, we will present alternative definitions for operator workload and conclude with what we believe to be the most useful working definition for Army applications.

Performance vs. Workload

Normally, performance is what we are ultimately concerned with: Can an operator successfully complete his or her part of the mission? One goal of workload analysis is to predict the worst performance-related outcome -- mission failure. Not only do we not want the mission to fail, we also do not want the soldier or machine to be damaged or performance to be degraded. Having anticipated and predicted a problem for performance or safety, a second goal is to correct those situations which produce the problem. As an aid in this effort toward better and safer performance, researchers have developed the concept of workload.

The hypothetical relationship between workload and performance is illustrated in Figure 2-1. In the figure, it can be seen that workload and performance seem to have an inverted-U relation. Performance can be adversely affected if OWL is too low as well as too high.

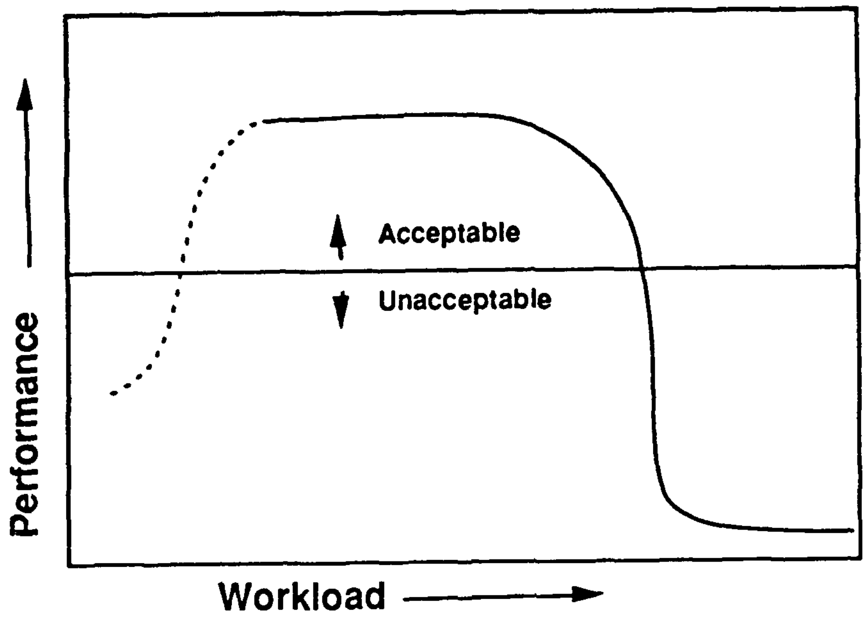

Figure 2-1. The hypothetical relationship between workload and performance.

- At extremely low levels of workload, the operator's capabilities are under-utilized and he or she may become bored and complacent. In these circumstances the operator can miss input signals and for that or related reasons become less proficient. (Although this pamphlet will not address cases in which workload is too low, it is well to note that performance can be adversely affected if OWL levels are extreme in either direction.)
- With intermediate levels of workload, performance can be expected to be acceptably high. Precise information is lacking on the range of "optimal" levels of OWL. What is known is that as task demands increase within this interval of workload, an operator can maintain performance standards by altering his or her strategy for responding to the demands of the task or by increasing his or her level of effort.
- As task demands become more extremely high, workload levels may exceed the operator's ability or willingness to commit more skill resources or to exert more effort. At that level

of workload, performance will decrease, perhaps, at some point or after some extended period of time, catastrophically.

Figure 2-1 also illustrates that workload is not the same as performance. Performance may remain at an acceptable level over a considerable range of workload variation, as illustrated in the driving example. In general, however, workload extremes are related to poor performance.

One of the goals of considering OWL in the system acquisition process is to uncover, identify, and eliminate those instances in which the demands of human tasks would degrade human and system performance. The important point is that many factors combine to determine tasks demands and the operator's reaction to those task demands. Attributes of the operator, the materiel system, and the operational environment all interact in affecting task demands, operator workload, and operator performance. These factors are discussed in the next section.

Factors Affecting Performance and OWL

It is generally accepted that operator performance is a function of two major kinds of factors: (a) external situational demands imposed on the operator, such as characteristics of the tasks that are, in turn, defined by the mission, the operational environment, and the design of the workstation, and (b) internal resources or characteristics of the operator that collectively determine his or her capability to effectively respond to the task demands.

Figure 2-2 illustrates these factors, all of which combine to influence how an operator responds and how well how well the operator responds to the ongoing demands. Workload analysis attempts to characterize the impact of these factors. The interaction of these factors will determine both operator workload and operator performance and, hence, system and mission performance.

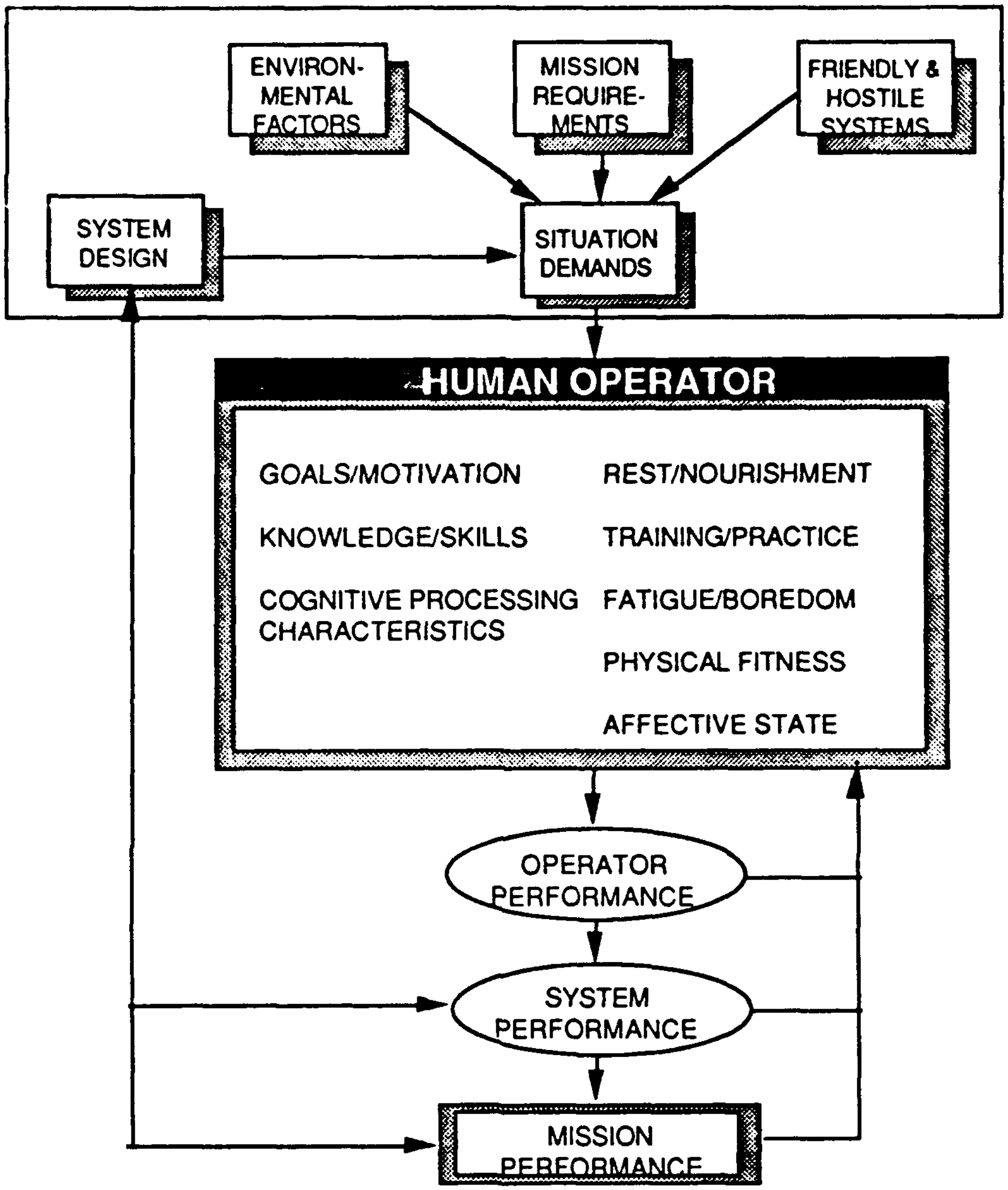

Figure 2-2. Influences on operator and system performance.

The upper portion of Figure 2-2 shows some of the external factors that influence OWL and performance. The system design, mission, and other external factors combine to create situational demands for the operator. In the middle of the figure is a representation of the system operator that identifies some of the internal factors which have a bearing on the operator's reactions to the situational demands. At the bottom of the figure are the performance consequences of the interaction of the situational demands and the operator reactions. Clearly OWL issues and concerns, as well as operator performance, are related to the interaction of these two major sets of factors.

This is the situation over which we wish to gain some control; it is complex but will yield to careful analysis. Stating that operator workload is a multidimensional concept may be correct, but tends to beg the question of what it is. While no single definition of workload is generally acceptable, one can appreciate the complexity of the concept by noting some of the attributes that have been ascribed to it from various sources. We do this in the next section.

Operator Workload Defined

Webster defines workload in the following ways:

> **workload** n 1: amount of work or of working time expected from or assigned to an employee. 2: the total amount of work to be performed by a department or other group of workers in a period of time (Webster's Third International Dictionary, 1976, p. 2635).

A scientific definition becomes much more detailed than just amount of work or of working time. The dictionary definition implies some outside entity which specifies the amount of work and the number of things to be done. However, we should also consider workload from the operator's viewpoint. Comparing the two viewpoints may yield much more information about workload than either viewpoint alone. Also, in addition to considering the individual operator, one can consider parts of the individual. Thus, one can analyze the amount of work done by the hands or by the eyes, or any other part of the body. A common and useful distinction is often made between physical and mental workload.

Individual operator workload may be related to personnel and training considerations; crew workload, to manpower considerations. At a basic level, the term workload carries a number of meanings within the military community, especially the second dictionary definition. For example, workload often is associated with the number, frequency, and durations of tasks performed by a specific number of Army personnel of particular military occupational specialties (MOS) and skill levels. It is clear in this context that workload does not refer to cognitive or physical underload or overload, but rather to task-based manning considerations. Obviously, care must be taken to specify clearly what is being discussed when using terms like workload and workload analysis. Crew workload and manpower requirements are closely tied to the potential cognitive overload of individual operators, but they are different and should be clearly differentiated.

It is clear that an operator's performance on a given task depends not only on the demands of the task and the situation in which it is embedded, but also on the ability and the willingness of the operator to respond to those demands. Workload is a multi-dimensional concept. Behavioral scientists have defined workload in a number of ways, each depending on the workload issue under study at the time. It has been related to the amount of things to be done, the amount of time available to do them, the amount of time over which they must be done, the capacity of the individual operator to accept additional work, physical effort required to perform a given task or group of tasks, and a number of other descriptions or combinations of descriptions. Generally, three broad kinds of meanings are used for workload. They are:

- amount of work and number of things to do,
- *time concerns, and*
- the psychological reactions or experiences of the human operator.

To summarize, recent workload research leads to several workload principles. They are:

- Workload is relative. It depends on both the external demands and the internal capabilities of the individual. It can vary over time and amount for an individual.
- Workload causes the individual to react in various ways. Workload is related to but not the same as the individual's performance.
- Workload involves the depletion of internal resources to accomplish the work. The higher the workload, the faster resources are depleted.
- There is a diversity of task demands and a corresponding diversity of internal capabilities to handle these demands. Persons differ in the amount of these capabilities that they possess.

Out of these principles we can derive a general definition of workload. We define workload as the **relative capacity to perform**. This working definition is meant to imply not only the amount of internal resources (or the spare capacity) available to perform mission essential tasks, but also the ability and willingness of the operator to use that capacity in the context of the specific personal and environmental situation.

By proposing a working definition as the relative capacity to perform, the emphasis is on predicting what the operator will be able to accomplish in the future. It is a global definition in that it does not necessarily attempt to identify the specific factors or dimensions that will influence individuals in their performance or their perception of workload. At all times, workload will involve the interaction of the operator with the task and these two elements cannot be separated totally. At the same time, the circumstance will dictate to what extent operator or task characteristics will be important in the assessment of workload. The specific situation will determine the most appropriate questions to ask about operator workload, and consequently the most appropriate ways to answer those questions.

CHAPTER 3. REVIEW OF OWL IN THE ARMY SYSTEM ACQUISITION PROCESS

The purpose of this chapter is to highlight references to operator workload (OWL) issues and concerns cited in documents that cover policies and procedures for system acquisition programs. The objectives are to (a) underscore the requirement to consider OWL issues and concerns in all phases of the Army system acquisition life cycle, and (b) establish that responsibility for considering OWL during the acquisition process is shared by multiple Army agencies and activities.

As will be emphasized in Chapter 4, the requirements and responsibilities for addressing OWL take on added importance due to recent emphasis on soldier-centered programs to improve the cost and operational effectiveness of materiel acquisitions. This emphasis is established in Department of Defense Directive (DODD) 5000.53, Manpower, Personnel, Training and Safety in the Defense System Acquisition Process, and in Army Regulation (AR) 602-2, Manpower and Personnel Integration (MANPRINT) in the Materiel Acquisition Process [MAP].

How OWL Issues are Currently Addressed

An examination was made of several key acquisition documents. While operator workload issues are addressed in some of these documents, there is not much specific discussion or guidance. This may be because the influence which OWL has on system performance has just recently been recognized for other than aviation systems. More discussion and guidance are provided in these documents if the area of interest is expanded to include issues related to workload (e.g., human factors, manpower, and personnel).

In addition to examining each document for workload-related issues and concerns, the required and related publications listed in each document were also identified. (A required publication contains information that is necessary to completely understand the referencing document; a related publication is a source of additional information but it does not have to be read to understand the referencing document.) By comparing workload-related information in these documents and their lists of required and related publications, a "document tree" was established, as shown in Figure 3-1. This "tree" identifies the documents which contain the most relevant Department of Defense (DOD) and Department of Army (DA) OWL guidance for system acquisition programs.

As described in its statement of applicability, AR 70-1 is the first in order of precedence for managing Army acquisition programs. For this reason it is highlighted in Figure 3-1. It implements DOD policies and establishes Army policy and procedures to govern the acquisition of major and non-major Army acquisition programs. It requires adherence to other more technically oriented ARs. Six of these other required ARs contain OWL-related requirements. These six ARs are shown in Figure 3-1, connected to AR 70-1 with solid lines. One of these, AR 602-2, is shown as having three required and two related publications that make reference to OWL-related concerns. One of the required publications, AR 602-1, requires adherence to two DOD-level documents which mandate attention to OWL concerns.

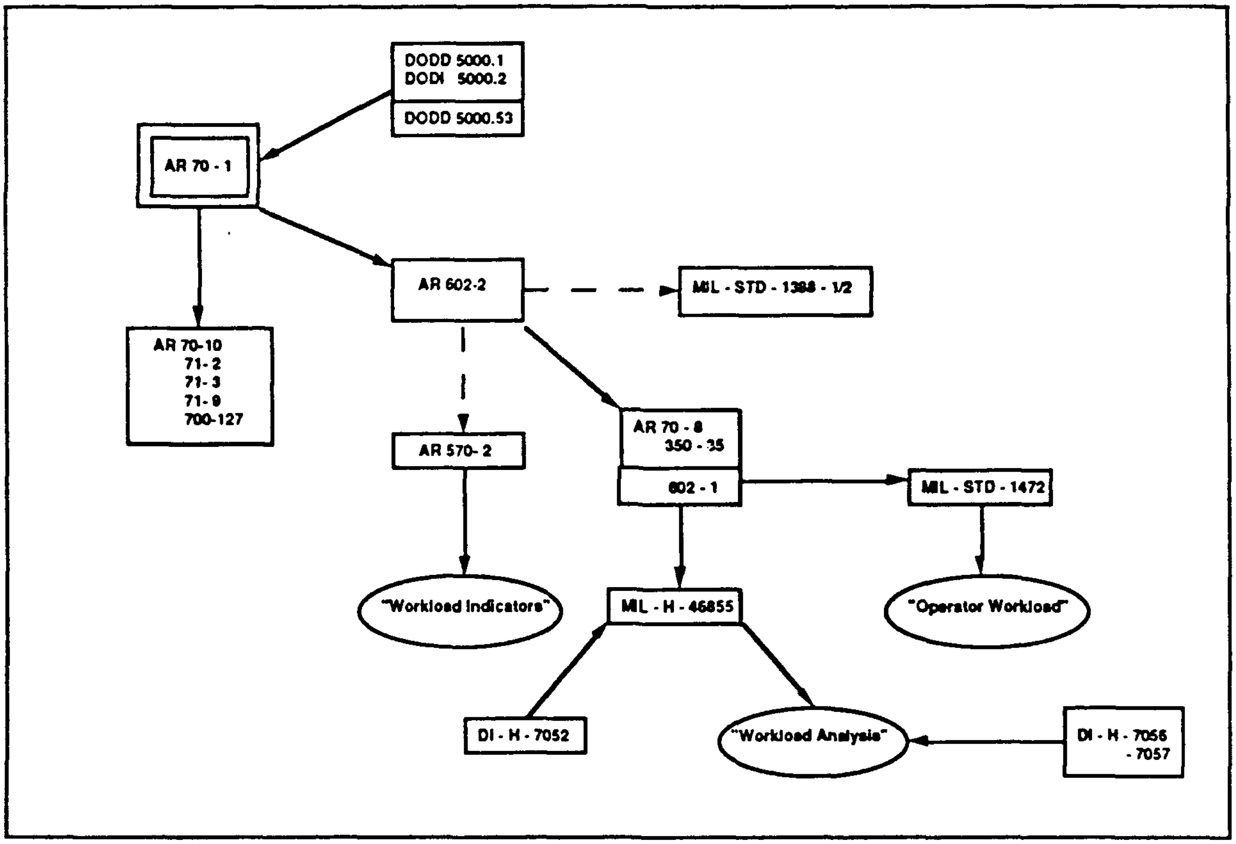

Figure 3-1. Relationship among OWL-Relevant Documents. (Solid connecting lines indicate required references; dashed lines indicate related references.)

As is suggested by the entries near the bottom of Figure 3-1, the term "workload" appears in only three of the documents. None of those three, AR 570-2, MIL-H-46855B, and MIL-STD-1472C (all described below), is preeminent in the hierarchy of documents that address the MAP. However, these three documents are, in turn, referenced by and consolidated into policy and procedures mandated by more fundamental and required publications. Furthermore, the workload-related language in all the publications shown in Figure 3-1 implies a requirement to incorporate operator workload issues and concerns into the Army system acquisition process.

Succeeding paragraphs describe the purpose of each of the documents shown in Figure 3-1, and their role in establishing requirements for consideration of OWL issues and concerns.

Department of Defense Documents

The two DOD Directives (DODD 5000.1 and 5000.53) and the DOD Instruction (DODI 5000.2) shown in Figure 3-1 do not specifically address OWL but do provide high level policy and broad guidance relating to major system acquisitions.

DODD 5000.1 and DODI 5000.2 are first and second, respectively, in order of precedence for providing policy and procedures and for managing defense acquisition programs. Two principles given in DODD 5000.1 are highly relevant to OWL issues. They state that (a) affordability, which varies in part as a function of the availability of manpower resources, shall be considered throughout the acquisition program and that there must be sufficient resources to support projected requirements, and (b) logistic supportability requirements, in the form of readiness goals and related design requirements and activities, shall be established early in the acquisition process and shall receive emphasis comparable to that accorded to cost, schedule, and performance objectives and requirements.

The procedures and requirements contained in DODI 5000.2 give equal emphasis to the qualitative and quantitative system performance parameters that are indicators of a system's operational effectiveness and those that are indicators of its operational suitability. While operational effectiveness is the overall degree of mission accomplishment of the system, operational suitability is the degree to which the system can be satisfactorily fielded and includes the requirement that the soldier be able to operate, maintain, and support the system. The latter requirement is clearly related to OWL considerations.

The recently published DOD Directive 5000.53 was established to improve the integration of manpower, personnel, training, and safety (MPTS) in all stages of the acquisition process, and to ultimately field more capable defense systems. It mandates that DOD shall ensure that all systems can be effectively operated, maintained, and supported by well qualified and trained individuals. Accomplishing this objective requires that human capabilities and limitations be fully considered early and continuously in the system design process.

Department of Army Regulations

Brief summaries of the OWL-related requirements in each AR shown in Figure 3-1 are given in succeeding paragraphs.

- **AR 70-1.** AR 70-1 establishes basic policies and procedures for Army system acquisition and emphasizes front-end planning and tailoring of the MAP to minimize the time needed to develop, produce, and field a system. A key objective and policy mandates a formal logistic support and MANPRINT program and evaluation strategy to ensure that optimally supportable systems are acquired. (See ARs 70-10, 602-2, and 700-127.)
- **AR 70-8.** AR 70-8 implements those portions of AR 70-1 which pertain to the Army personnel performance and training program areas of concern, and covers portions of the Army research, development, test and evaluation program which deal with attaining more effective use of military personnel and increasing personnel proficiency.
- **AR 70-10** and **AR 71-3.** These two ARs establish policies and prescribes procedures for testing and for continuous comprehensive evaluation (C2E) to support decision reviews of the MAP. User testing is to be conducted in as realistic an operational environment as possible, using the types of operational and support personnel that are expected to use and maintain the system when it is deployed. User testing is conducted to estimate both operational effectiveness and operational suitability, and to provide information on the adequacy of doctrine, organization, operating techniques, tactics, and requirements for personnel and training.

- **AR 71-2.** AR 71-2 defines policies, procedures, and responsibility for the basis of issue plans (BOIP) and qualitative and qua:.:'tative personnel requirements information (QQPRI) during the .MAP. The BOIP addresses the number of new items of equipment and personnel to be included in organizational documentation. The QQPRI is a compilation of information used to determine the need to establish or revise job specifications (based, in part, on factors such as the levels of knowledge, creative ability, and concentration required for successful performance in the duty position), and to prepare plans to provide the personnel and training needed to operate, maintain, and support the new or improved materiel system or item of equipment.

- **AR 71-9.** AR 71-9 establishes policies, procedures, and responsibilities for preparing requirements documents to acquire materiel systems and training devices. It directs the combat developer to establish system performance requirements that include MANPRINT considerations.

- **AR 350-35.** AR 350-35 addresses new equipment training (NET) required to insure that qualified personnel will be available to conduct training and to operate and support the equipment during its development and fielding. NET planning considerations should include the technical complexity of the new equipment and the quality of personnel to be trained.

- **AR 570-2.** AR 570-2 addresses objectives and procedures for the development of manpower requirements criteria (MARC) for combat support and combat service support positions in table of organization and equipment (TOE) units. A MARC study is conducted to produce a "workload indicator", which represents an estimate of the product of the productive (hands-on) time required to perform a unit of work and the number of times that work unit must be performed during sustained combat operations.

- **AR 602-1.** AR 602-1 integrates human factors engineering (HFE) throughout the MAP. The scope of HFE includes determining projected manpcwer, personnel and training capabilities and limitations. An objective of the HFE program is: "to insure that materiel systems are developed so that the personnel tasks involved in operation, maintenance, [and support] do not exceed available or achievable soldier capabilities" (p. 1-4). It stipulates that the HFE program shall be performed in accordance with MIL-H-46855B, thereby, as will be shown below, establishing a requirement for an OWL analysis.

- **AR 602-2.** AR 602-2 establishes policies and procedures for the MANPRINT program, emphasizes front-end planning of soldier-materiel system design, and establishes the requirement for the system MANPRINT management plan (SMMP). MANPRINT refers to the comprehensive management and technical effort to ensure total system effectiveness by continuous integration into the materiel development and acquisition of all relevant information concerning HFE, manpower, personnel, training, system safety, and health hazards. AR 602-2 addresses the concept of workload as follows: "... analyses of the work environment also includes consideration of the physical and cognitive demands on personnel ..." (p. 3), and "Ensure through studies and analyses and basic and applied research ... that equipment designs and operational concepts are compatible with the limits of operators and maintainers defined in the target audience descriptions." (pp. 3 and 4) Thus, specification of MANPRINT analysis requirements includes specifying OWL analysis requirements within the appropriate problem domain.

- **AR 700-127.** AR 700-127 prescribes guidelines for the management of integrated logistic support (ILS). One objective of ILS management is to ensure that plans and procedures are developed to integrate accepted MANPRINT principles and processes with full consideration of the 12 individual logistic support elements. Individual ILS elements include one for manpower and personnel and one for training and training devices. It is recognized that trade-off may be required among ILS elements in order to acquire a system that is affordable, operational, supportable, and sustainable within the resources available. AR 700-127 prescribes that logistic support analysis (LSA, see MIL-STD-1388-1) is required in all acquisition programs to provide uniform methods in the application of ILS and MANPRINT influences in system design and selection. It further specifies that the logistic support analysis record (LSAR, see MIL-STD-1388-2) is the standard medium for systematically recording, storing, processing, and retrieving data used or developed during the LSA process.

Military Specifications, Standards, and Data Item Descriptions

- **MIL-H-46855B.** An explicit reference to operator workload in DOD-wide documents is contained in the military specification, MIL-H-46855B, Human Engineering Requirements for Materiel Systems, Equipment and Facilities. The purpose of this specification is to establish and define an effort that encompasses analysis, design and development, and test and evaluation. The analysis requirements deal primarily with task analysis, function allocation, and estimates of potential operator and maintainer information processing capabilities. In one section it specifically mandates the following:

"3.2.1.3.3 Workload Analysis - Individual and crew workload analysis shall be performed and compared with performance criteria." (p. 5)

However, no further information is given relative to how to perform such an analysis nor what performance criteria should be used. This military specification contains in its appendix an application matrix that gives guidelines as to what sections of the specification should be applied during what phases of the life cycle as well as what modifications should be made depending on the life cycle phase. The MIL-H-46855B appendix shows that specific workload analysis provisions are in effect in all phases of the life cycle.

- **MIL-STD-1388-1** and **MIL-STD-1388-2.** These two military standards provide a uniform set of logistic support analysis data requirements, methods, and documentation formats. The performance of certain LSA tasks will generate, analyze, and document ILS-related MANPRINT information for individual materiel acquisition efforts. While none of these tasks specifically address OWL, those with the most applicability to OWL issues and concerns are likely to be Task 201 (Use Study), Task 203 (Comparative Analysis), Task 301 (Function Requirements), and Task 401 (Task Analysis). All these tasks require the identification of uses and requirements of the new system, to include those related to manpower, personnel, training, and human performance capabilities and limitations.

- **MIL-STD-1472C.** This is the basic military standard for human engineering design criteria and a document in which designers should look for guidance. The general requirements for equipment design include the following principle: "Design shall be such that operator workload, accuracy, time constraints, mental processing, and communication requirements do not exceed operator capabilities" (p. 17). Other OWL relevant requirements state the software is to be designed to minimize task complexity and memorization, and that the distribution of workload should be such that none of the operator limbs are overburdened. While the requirements to perform OWL analyses is incontroversial, there are no specific suggestions on how to do such analyses and, interestingly, the term "workload" does not appear in the index of the published standards.

- **Data Item Descriptions (DIDs).** In general, DIDs describe data and prescribe preparation instructions for data that are required by military specifications and standards. There are a series of DIDs that call for a wide range of information in the area of humans factors. The specific DIDs shown in Figure 3-1 contain requirements for implementation of the workload analysis. DI-H-7056 and DI-H-7057 address soldier-equipment interface and task analysis data required for system operators and maintainers, respectively. DI-H-7052 contains specific provision for the use of dynamic simulation for workload analyses.

Responsibility for Workload Issues and Concerns

Each of the ARs shown in Figure 3-1 establishes and delineates responsibilities for administering, executing, and managing the policies, procedures, and guidance it incorporates. With regard to the totality of the regulations and to those portions of the regulations that pertain to workload issues and concerns, those with responsibility are located across and quite broadly within the Army general staff, major commands, and other Army elements.

At the top of the organizational structure, the assistant secretary of the Army (ASA) for research, development and acquisition is the principal DA staff element for the execution of Army acquisition executive (AAE) responsibilities. These responsibilities include the establishment of a streamlined acquisition structure for managing acquisition programs, ensuring that programmatic decision authority rests only in the AAE - program executive officer (PEO) - program or project manager (PM) chain.

A key responsibility that flows through the streamline management structure is supervision of the integration of MANPRINT and ILS. The ASA for manpower and reserve affairs coordinating with the DA Deputy Chief of Staff for Personnel and the ASA for installations and logistics in coordination with the DA Deputy Chief of Staff for Logistics monitor and ensure that MANPRINT and ILS considerations, respectively, are incorporated into the Army materiel system requirements, development, acquisition, tests, evaluation, and fielding.

The Army War College, in its excellent text, Army Command and Management: Theory and Practice, describes the essential role played by the materiel developer and combat developer (MATDEV/CBTDEV) "team" in the MAP. The MATDEV/CBTDEV team is the terminology used to describe the informal but essential and close working relationship among two major Army commands, Army Materiel Command (AMC) and Training and Doctrine Command (TRADOC), and other players in the research, development, and acquisition management process. Generally, the AAE/PEO/PM chain in conjunction with AMC is the principal MATDEV. TRADOC is the principal CBTDEV, as well as the principal trainer and training developer, and formulator of doctrine, concepts, organization, and materiel requirements and objectives. TRADOC also represents the user (i.e., the gaining major commands) in the MAP. Working within their own commands and together, the MATDEVs and CBTDEVs are responsible for ensuring that ILS and MANPRINT requirements and considerations are coordinated and included in materiel system acquisition plans, solicitation documents, source selection evaluation criteria and procedures, contracts, and in the review and evaluation of contractor products and performance throughout the system acquisition process.

Other Army elements with major areas of responsibility in the MAP, and hence for the incorporation of workload issues and concerns into the system acquisition process, include the U.S. Army Operational Test and Evaluation Agency (OTEA) and the U.S. Army Logistics Evaluation Agency (LEA). OTEA supports the materiel acquisition and force development processes through overall management of the Army's user test and C2E programs. These independent test and evaluation programs include support and MANPRINT requirements and considerations. LEA serves as the logistician in the MAP, providing independent ILS supportability assessments for new and improved systems. Both OTEA and LEA provide advice and assistance to DA staff elements.

The Army elements named above are principally responsible for prescribing, coordinating, executing, reviewing, and approving the implementation of Army policy and procedures for system acquisition programs. Since those policies and procedures incorporate consideration of soldier capabilities and limitations, it is clear that the named agencies, along with their subordinate and support elements, share in the responsibility to ensure that OWL issues and concerns are incorporated into the system acquisition process.

Summary

This review of key military documents underscores Army requirements for addressing OWL and OWL-related issues and concerns during the MAP. It supports the conclusion that attention to OWL issues and concerns is required for all Army materiel acquisition and materiel improvement programs. OWL analysis is specifically called for in military specification MIL-H-46855B and system design requirements addressed in MIL- STD-1472C specifically include OWL considerations. Workload indicators defined in terms of manpower requirements are essential components of the products prescribed by AR 570-2. OWL issues and concerns take on added importance because of recent emphases on soldier-centered programs to improve the process of designing, procuring and fielding materiel systems, as established in DODD 5000.53 and AR 602-2. The responsibility to ensure that OWL issues are addressed is broadly spread across DA elements and agencies, all major commands, and other Army elements.

The importance of OWL issues and concerns in military acquisition programs may not have been immediately obvious. This is in part due to the fact that high level DOD and Army directives subsume OWL issues and concerns under the more general requirements to consider the soldier and human factors issues and supportability issues in acquisition programs. Coupled with this is the fact that until recently, with the advent of programs for MPTS and MANPRINT, soldier and human factors issues have not always received their required attention. This may be especially true for workload analysis, which has not been as well developed as other more traditional human factors analyses.

CHAPTER 4. MANAGING OWL DURING SYSTEM ACQUISITION

Thus far, this pamphlet has defined operator workload (OWL), described the relationship between OWL and system performance, discussed factors which affect the form of that relationship, and reviewed regulatory requirements for addressing OWL. However, our understanding of OWL and its effects on system performance are only of academic interest if that understanding cannot be used to influence system design and evaluation. This chapter discusses specific actions required to manage OWL during the acquisition process. These actions include:

- Defining OWL issues and concerns
- Assessing OWL during the acquisition process
- Integrating OWL into the system acquisition program

Successful integration of OWL issues and concerns into an acquisition program may not be easy. Criteria for establishing OWL requirements and specifications are not normally available. Subtle differences in the conditions which constitute OWL extremes, and individual differences in operator performance at OWL extremes can make examining and evaluating OWL a complex, time consuming, sometimes imprecise process. The current state- of-the-art for evaluating OWL and limited options for responding to OWL-induced problems further compound the difficulty of integrating these concerns into the acquisition process.

Nonetheless, OWL issues and concerns, OWL assessments, and other OWL-related events must be integrated into the earliest conceptual stages of the system acquisition process as well as the later development and deployment stages of the process. These OWL-related activities are not limited to only traditional materiel system design and evaluation matters. They are best considered in concert with the Army manpower and personnel integration (MANPRINT) initiative. A thorough and continuous MANPRINT analysis of the system of interest will incorporate OWL analyses. Finally, the mechanism for integrating OWL-related activities into the system acquisition process already exists in the system MANPRINT management plan (SMMP), the management document required for implementing MANPRINT during the materiel acquisition process. (MAP).

Defining OWL Issues and Concerns

The development of hardware concepts in response to materiel deficiencies provides the first opportunity to influence materiel system design with OWL-related information. Workload issues and concerns are critical in light of the fact that while more and more high technology is being incorporated into modern military systems, there is also an emphasis on not increasing the skill requirements of operators and on reducing the manpower and training burdens on system life cycle costs. Since these emphases are all likely to influence and be influenced by OWL, definitive statements that address OWL requirements are needed.

Statements used to define the requirements for a new or modified system, such as those found in an operational and organizational (O&O) plan and required operational capability (ROC) document, are broad, relatively generalized statements which address future needs. ROC requirements are typically stated in performance bands which address gross physical and operational characteristics (speed, accuracy, weight, volume, etc.) and system constraints (operating environment, survivability, mobility, etc). Impact on all MANPRINT domains is considered, most notably manpower constraints, personnel constraints, and human factors considerations.

These are the system requirements from which OWL issues will grow. Specifically, if the workload imposed upon or experienced by a human operator due to system requirements is excessive, the operator's capacity to perform may be exceeded, and the operator and system performance will be adversely affected. However, while most Army managers readily accept and respond appropriately to limitations in the performance capabilities of materiel components of a system, there is often some difficulty and an inappropriate response to possible limitations in the performance capabilities of human components of the system.

A Digression on Limits

When the notion of capacities or limits is considered in the context of a purely material system there is general agreement that the design of the system will be constrained so as not to exceed the capabilities of its hardware (and software) components. For example, an artillery tube has capacities that determine the size of rounds and amount of charge it can accommodate, and a computer has storage and processing speed limits. In these cases, the total system objectives and design will be constrained by the limits specified for one or more physical attributes of the system. Otherwise, the physical system will not be able to fulfill its mission. For example, the field artillery tube will not accommodate the ammunition provided or will explode if the charge is too large, and the computer will not be able to accommodate the amounts of data it was to process or will be too slow to provide timely output.

When the concept of limits is applied to the human component of a larger system, the same general principle must apply. And this is what the concern with workload is all about, ensuring that the system objectives and design do not exceed the soldier's capability to perform. And, it must be recognized that while the human component of a soldier-materiel system is more flexible than any hardware or software component of the system, the soldier too has limited capabilities to perform.

If the concern is with strictly physical and biomechanical capabilities and limitations of the soldier, there are reasonably good data on how the system design must be constrained to accommodate these human attributes. Here the concern may be with human characteristics such as the g-forces an operator can tolerate, both in terms of peak and sustained g-forces, before there is a danger of loss of consciousness. Alternately, the solider's limitation may be the force an operator can apply to a control lever before there is a breakdown in physical strength or the amount of rest required to recover from an extended period of excessive work demands. There is a general awareness and appreciation of potential workload problems, assessment techniques, data, and expected impact of these types of human limitations on system design and development. There is also, for these physical attributes, an awareness that the limits vary as a function of both inherent and experiential differences among people, and that they vary as a function of operational conditions. Consequently, system designers and developers know that there are variations in the database and these are taken into account in specification of soldier-system interface criteria.

If the concern includes limitations in human cognitive or mental capabilities, there is less agreement in how we are to assess the attribute of interest, less hard data to use in defining limits, and less reliable bases for predicting the impact on system performance of exceeding these limits. It is known that there are limits in the capability of humans to process information. We know what some of these limits are and have anecdotal information on others. For example, there are human limits in the ability to perceptually discriminate among variations in colors, to simultaneously attend to multiple auditory messages, or to maintain a high level of alertness over extended periods of operation.

What happens if the limit is exceeded, if too much "stress" is placed on a soldier's mental capacities? The soldier may confuse variations in a color-coded display (and the messages they were to convey), effectively reduce the auditory input overload by arbitrarily filtering out all information input that exceeds the processing limit or disregarding only certain classes of information (e.g., actually turn off the radio net to higher command), or regress to performing simple over-learned behaviors even if they are inappropriate.

The problem is that we lack guidelines for defining limits in information processing capabilities, assessing cognitive workload levels, or predicting the consequences of mental workload as we have for purely physical workload. But, that is precisely why extensive testing is needed to ensure that a design matches the capacity of the soldier to perform. Information on OWL issues and concerns must be acquired now for systems in development or undergoing modification because there is a limited database upon which decisions can be based. Over time, ongoing efforts to address OWL issues and concerns will generate the database that will aid in future system acquisition programs.

Development of Specific OWL Concerns

Since OWL requirements are not easily quantifiable there is a great temptation to express them in general terms such as "Operator workload will not adversely affect system performance". These statements recognize the importance of OWL but are of little value to the design engineer or human factors practitioner who is designing to OWL requirements, evaluating OWL impacts on performance, or suggesting system engineering and design improvements. Such statements express objectives and what is needed is an OWL plan to meet those objectives.

Rather than starting with an attempt to define OWL requirements for a new or improved system, it is recommended that defining specific OWL concerns be the first step in establishing control of OWL during the acquisition process. These concerns are major risk areas that, if not resolved, could cause major problems in meeting system performance requirements.

The emerging requirements for the physical features of a new or improved system need to be compared with those that existed for earlier systems and system components, and the role of the operator of those systems need to be carefully examined. The critical questions for addressing OWL issues and concerns would include the following:

- Is there reason to believe that OWL will be a problem?
- During which portions of the mission scenario are OWL problems likely to emerge?
- What will be the nature of expected OWL problems?
- Will these problems become more severe as scenarios become more realistically rigorous?

Answers to these questions will drive OWL requirements. They may lead to specific OWL-related language. At a minimum, the answers should reveal how OWL considerations might affect system performance.

It needs to be emphasized, however, that the answers will not necessarily be obvious nor easily determined. For example, in answering the first question posed above, it should be noted that few systems operate with no human interface; even "automated" systems require a human monitor. Furthermore, even if the system tasks allocated to a human operator do not impose any significant demands on the operator, they may, in combination with other tasks required of the operator, lead to OWL problems. The effects of adding together relatively simple task demands are described and illustrated in Chapter 2 for an automobile driving task and a purely mental task.

The second question raised above should force an Army manager to consider not only the possible depletion of an operator's ability and willingness to respond as required over the length of a sustained operation, but also the need for an operator to endure fluctuations in workload extremes over an extended mission -- from long periods of boredom to brief periods of abject terror.

The third question on the nature of a potential OWL problem also may not be simply addressed. Does a workload problem arise because there is too little time to do what must be done, too many things to be done, or a combination of both of these problems? Is a potential workload problem the result of extremes in demand in the physical, mental or emotional aspects of the task; is it due to extremes in information processing load in the visual, auditory, memory, or some other channel? Under what conditions is the OWL problem most severe? Does the OWL problem exist for all potential operators or for only certain definable types of soldiers?

The OWL issue raised in the fourth question, the realism of the training or battlefield scenario, is often not adequately considered. An analysis of OWL issues must take into account all the tasks that may be imposed on an operator over a meaningful set of operational situations. For example, what might be the impact of a new system or subsystem on the representative operator's capability to perform all tasks required of him or her during an exercise, to include such tasks as land navigate, command and control, communicate with higher, adjacent, and subordinate elements, and employ (other) weapon systems. The point is that even a "simple" system must be operable by the human element of the larger system without degradation in other functions.

However difficult it may be to define and successfully address relevant OWL issues and concerns, this activity must be performed. The sooner it is performed during the acquisition process the better. If this activity is not performed early during the acquisition process, there might not be another chance to influence OWL within the process.

Assessing OWL

A variety of OWL assessment techniques have been developed in the scientific community and are available to be applied to OWL analyses of Army systems. A great deal of scientific and practical information is available --The References section lists some publications which describe recent research and analyses using some of the more widely accepted OWL assessment techniques.

It could be argued that the particular OWL assessment program that is most appropriate for a given system acquisition program is a "technical" matter best left to "experts" in the human factors, behavioral science, or test and evaluation areas. It may be true that the details of the assessment program are not necessarily a matter that will demand attention from the management level decision makers. It is also true that the planning required to execute an OWL assessment program requires that the manager have at least some knowledge of how the assessments can be done.

Three points need to be made in this regard:

(1) There are workload methods that can be used in every stage of the acquisition process, even in early concept development. If the hardware system of interest does not exist during early stages in the acquisition processes, or if the emerging hardware and doctrine are only in mockup or draft form, workload issues can still be examined by use of appropriate analytical or predictive techniques.

(2) No one technique will tap all potentially relevant aspects of OWL for a given system in a particular set of environmental situations. It is therefore recommended that a battery of OWL assessment techniques be used; an OWL assessment program should be implemented that will utilize the strengths of different types of techniques and assessment procedures.

(3) There are automated tools available to assist the MANPRINT, human factors, or workload analyst in choosing the most appropriate OWL assessment method. The Army Research Institute (ARI) has developed the OWLKNEST (Operator Workload Knowledge-based Expert System Tool); the National Aeronautics and Space Administration (NASA) has developed the WC FIELDE (Workload Consultant for Field Evaluations) expert system. OWLKNEST is oriented to workload evaluations under field conditions and provides information about measures that can be used for both prediction and evaluation throughout system development. WC FIELDE addresses evaluation techniques developed for use in primarily laboratory and simulator environments.

Broadly, OWL measures can be characterized as analytical or empirical. Some analytical methods are listed according to type in Figure 4-1. Analytical methods are appropriate when soldier-in-the-loop assessments are not possible, or would be too costly and time-consuming, given other program constraints.

- Analytic
  - Comparison
  - Expert Opinion
  - Math Models
    - Manual Control
    - Information Theory
    - Queueing Theory
  - Task Analysis Methods
  - Simulation Models

Figure 4-1. Analytical OWL assessment techniques.

The comparison techniques assess the OWL of an emerging system by relating it to the OWL associated with a predecessor system. Expert opinion techniques involve the elicitation of OWL estimates from system operators or other system experts. Mathematical models represent attempts to abstract and quantify aspects of the operator-system interface through the use of formal mathematical representations and relationships. Task analysis techniques are based on detailed decompositions of the intended missions of a system into individual tasks of the operator. Simulation techniques for assessing OWL are essentially extensions of task analysis methods in which the behavior and performance of an operator are modelled and simulated in a computer program.

Analytical methods are generally associated with predicting OWL early in system development where the greatest design flexibility is available with the least impact on system cost. However, the analytical techniques may also be used throughout the system acquisition process to guide, augment, or extrapolate beyond soldier-in-the-loop investigations. They are, however, not tied to actual soldier performance. Therefore, these methods should be corroborated through the use of other methods, or validated with empirical data.

Figure 4-2 lists empirical OWL assessment techniques. They are soldier-in-the-loop methods which, as the name implies, require an operator using actual hardware, system prototypes, or system simulators.

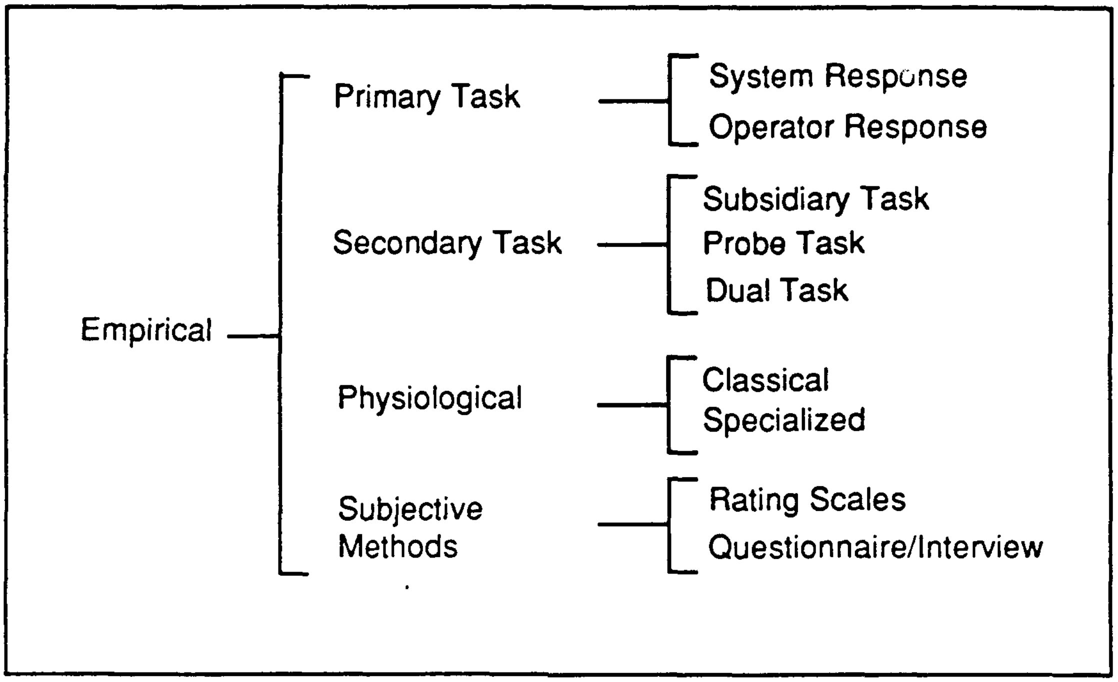

Figure 4-2. Empirical OWL assessment techniques.

Primary task methods relate workload directly to operator and system performance. Secondary task methods use performance of a secondary task, either a part of the operating procedure (embedded tasks) or some extra task (not embedded), to assess the amount of spare capacity available. Physiological techniques use some physiological measure, such as heart rate or eye movement, which can be related to workload. Subjective measures, e.g., rating forms, questionnaires, or interviews, are typically administered to subject matter experts or operators during or after missions to assess OWL.

The empirical techniques have received considerable attention in the scientific community. These techniques have been shown to vary considerably in their sensitivity, and in the cost and expertise required for their application. The demands for realism and other data collection requirements and constraints frequently make subjective measures, using post mission data, the measures of choice during typical military testing of emerging or modified systems.

The References section lists publications which present detailed information concerning these techniques. Expert systems such as OWLKNEST can be of considerable assistance in developing effective batteries of tests for administration in each stage of the acquisition process. The Army manager and OWL analyst both should be sensitive to the need to develop an assessment battery which not only identifies whether or not workload is a problem, but also the nature of the problem (e.g., time available or mental demands).

Integrating OWL into the System Development Program

It has already been said that OWL issues and concerns need to be addressed throughout the acquisition process. It should be done iteratively, generally relying on predictions using analytical assessment techniques early in the cycle, and empirical evaluations later in the process. Figure 4-3 illustrates stages in which OWL related information should be influencing the process. The results of OWL predictions should influence the development of design criteria and program documentation from the earliest development stages. As hardware becomes available, the analyst should rely more heavily on soldier-in-the-loop evaluations. OWL evaluations assess the degree to which design criteria and specifications have been met. As suggested in Figure 4-3, analytical methods may still be appropriate late in the cycle for assessing the effectiveness of proposed product improvements.

The importance of early assessment of OWL and its system impacts cannot be overemphasized. A commonly accepted rule of thumb holds that 70 percent of life cycle costs are set before the system enters the demonstration and validation phase. OWL can impact and be impacted by many facets of a system, to include personnel, manpower, and training issues. The potential complexity of responding to OWL system weaknesses makes early assessment and design influence particularly critical.

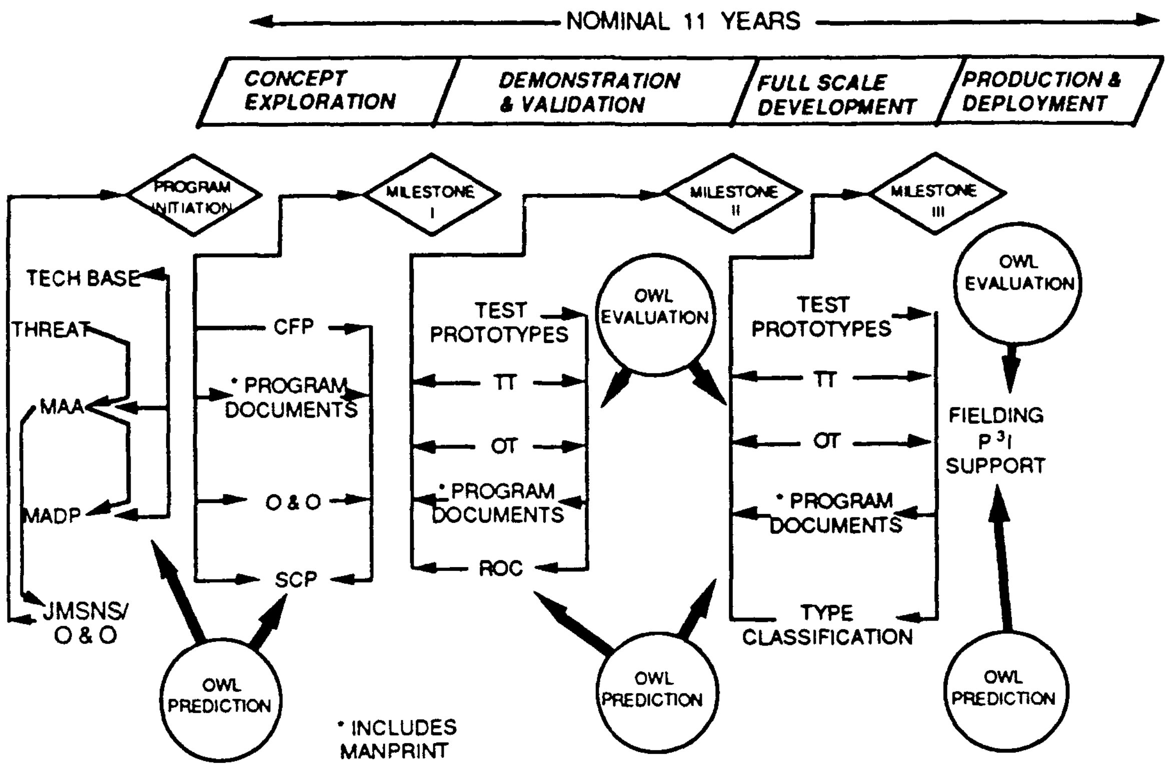

Figure 4-3. OWL considerations in the traditional MAP

Accelerated acquisition strategies are becoming more common. The implementation of strategies such as the Army streamlined acquisition process (ASAP), and adoption of non-developmental items (NDI) are examples of these accelerated strategies. Figure 4-4 illustrates stages in the ASAP in which OWL assessments should influence the development of the system. The accelerated strategy can be both a boon and an obstacle. Generally, NDI strategies make hardware available early in the program for empirical evaluation. Experience with commercial applications can also provide insight to OWL-related issues. Conversely, the accelerated strategies minimize test-fix-test iterations, and thus make early and thorough OWL assessment more critical.

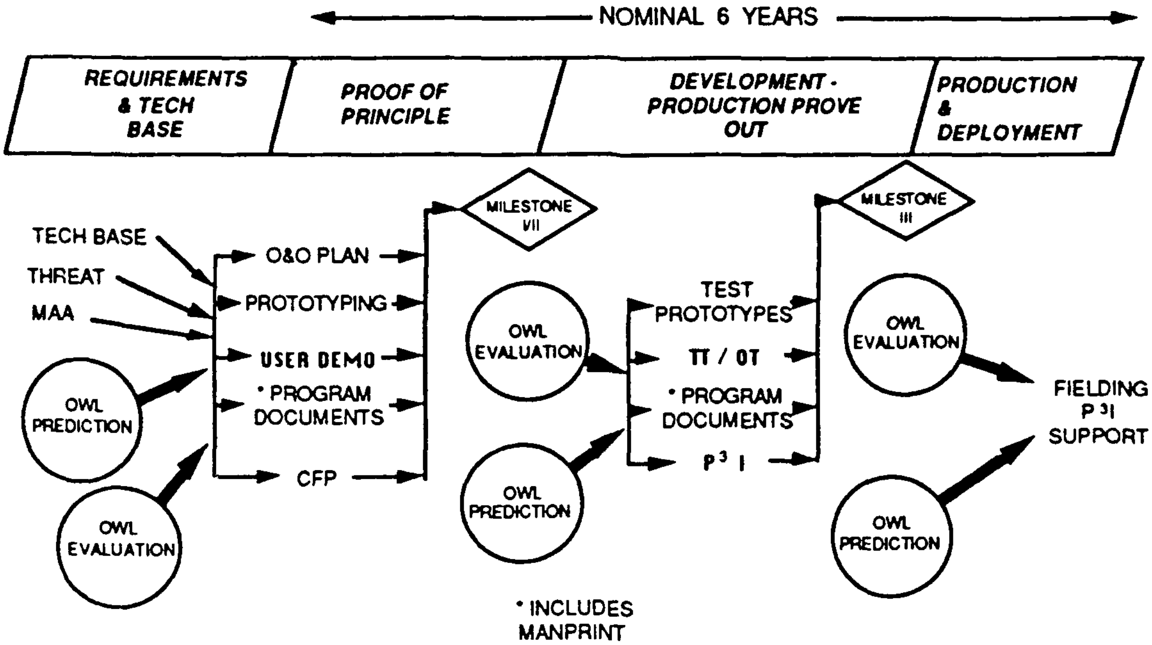

Figure 4-4. OWL considerations in the ASAP.

The *Army MANPRINT initiative is the key to integration* of OWL considerations into the acquisition process. The philosophy of the MANPRINT program is to have the Army and industry take necessary actions to ensure an affirmative answer to the question: Can this soldier, in this unit, with this training, perform these tasks to these standards under these conditions? The MANPRINT program includes but is not limited to the integration of all actions in the MAP affecting human performance and reliability, to include manpower levels, personnel requirements, training requirements and methods, human factors engineering, system safety, and health hazards.

Interrelationships between OWL and MANPRINT Domains

Manpower, personnel and training (MPT) are three critical considerations during the Army MAP. Manpower is concerned with force structure. It deals with how many people of what military occupational specialty (MOS) are needed to operate, maintain, and support the system. These are sometimes referred to as the "spaces." Personnel issues deal with the kind of people needed to operate, maintain, and support the system. People in this context are recognized as possessing different levels of intelligence and skill, as well as different personality attributes. Personnel issues are sometimes referred to as the "faces," implying the individual characteristics of the soldier. Training, of course, is the instruction of the soldier in specific skills and procedures needed to perform necessary tasks. Training is done in schools and in units and many training methods are used. While none of these concerns is synonymous with OWL, there are interrelationships between OWL and MPT that should be kept in mind during development.

Manpower issues are often related to OWL by way of task timeline relationships, i.e., time required to perform a task vs. the time available, or in terms of only physically oriented workload concepts. In this respect it may be appropriate to conclude that if there is too much for one person to do in a certain amount of time to specific criteria levels, then having two people do the job will take care of the problem. However, this relatively simple addition of more people (assuming that the additional people with the needed abilities are available) will not solve every problem. Some tasks are holistic and cannot be divided among a group of individual operators. For example, the mental processes of perceiving targets, processing information, and making engagement decisions often must ultimately rely on the activities of an individual operator, not on crew activities. Adding another person in such a case would not help performance, and the mental workload of the operator will not be reduced by additional manpower.

Also, there is increasing emphasis on reducing manpower requirements. This factor is, at once, a driver for developing ways to increase human productivity, and a root cause of increasing concern regarding the impact of OWL. The distinction between manpower and OWL concerns may be made by asking: (a) are the tasks creating "workload" the kind that can be solved by just adding another person or (b) is the nature of the task such that it must be done by an individual and requires too much in too short a time period? Each problem may require a separate set of solutions.

Personnel issues included individual characteristics of the soldiers. The interrelationship between OWL and personnel issues involve tradeoffs between soldier quality (as identified, say, by the Armed Services Vocational Aptitude Battery, ASVAB) and the degree of soldier perceptual, cognitive, or psychomotor loading caused by system tasks. Tradeoffs may need to be identified among the types of soldiers available and the workload demands of different system designs and different operational environments. Like manpower considerations, it is only sometimes true that a workload problem can be solved by a more capable soldier.

Training is another MANPRINT domain with which OWL is interrelated. Increased training gives the soldier knowledge, skills, and practice in the required tasks. Additional training may be and is frequently treated as the solution to overcome inadequate performance. However, training often may not be effective in reducing workload, nor a cost-effective way of enhancing performance. To adequately control the more cognitive aspects of workload, there may need to be tradeoffs among the amount and type of training and the quality of the soldier. An alternative to more or different types of training could be a change in the design of the system.

The other three MANPRINT domains are also related to OWL issues and concerns. Human factors engineering (HFE) is concerned with aspects of the engineering design that impact on the soldier-system interface. OWL issues are clearly interrelated with HFE issues. If an interface has been designed well, the ease with which the operator can perceive information or perform motor tasks may be optimal, thereby reducing workload. A poorly designed interface may be the major factor in creating a workload-intensive task. Human factors engineering solutions should be among the first pursued when overload problems are identified.

Health hazards are any conditions inherent in the use of a system that may cause degradation of job performance due to chronic disability or death of the operator. Health hazards include toxic substances, vibration, noise, temperature extremes, and psychological stressors. Although this last area is not universally considered a health hazard, psychological stressors, such as confined spaces, isolation, sleep deprivation, and cognitive overload, may cause chronic disability of system operators and serious degradation in job performance. Health hazard assessments are designed to identify potential problems early in the acquisition process and to raise a flag that health issues must be considered as the MAP continues. OWL issues should be related to health issues in the acquisition process.

System safety is concerned with identifying and eliminating or reducing the risks associated with system (particularly hardware) characteristics that may cause accidental injury or death. The results of hardware failure such as electrical shorts, failure of restraint harnesses, or toxic fumes are of concern. OWL issues are related to the safety of the system to the extent that these risks intrude on and occupy the operator. Conversely, an overloaded operator may make errors that create dangerous conditions.

In summary, operator workload relates to all six MANPRINT domains. It is not synonymous with, nor will it fall under the exclusive purview of, any particular domain. However, the interrelationships between OWL issues and the MANPRINT domains, and their joint influence on system performance are important considerations in developing and implementing system requirements. Considerations of these interrelationships are critical steps in integrating OWL issues and concerns into the system acquisition process.

The Army specifies in its training courses on MANPRINT that workload analysis is to occur in all phases of the acquisition process to assist in answering such questions as:

- Which design alternative is the best?
- What is the best allocation of tasks and jobs among the operators?
- What training will be required?
- Can operators perform all tasks effectively?
- What design inadequacies exist that must be rectified?

These questions as well as others are raised during the various phases of the acquisition process, as appropriate, and workload assessment techniques must be employed to provide timely answers.

System MANPRINT Management Plan

The system MANPRINT management plan (SMMP) is the keystone for integrating OWL considerations into the system acquisition process. It is the "planning and management guide and an audit trail to identify tasks, analyses, tradeoffs, and decisions that must be made to address MANPRINT issues during the materiel development and acquisition process" (AR 602-2, p. 12).

The SMMP is initiated by the combat or training developer and requires consideration of concerns and questions that may affect soldier performance in Army equipment. Therefore, it is an appropriate and logical place to include OWL concerns. The SMMP has the important attribute of being initiated at the very outset of materiel requirements development. It is to be started prior to the program initiation, and should be developed prior to or concurrently with the O&O Plan. At this point, OWL concerns can be raised and methods to answer questions and address concerns can be suggested.

The format for the SMMP is given in an appendix of AR 602-2. The five major sections of a SMMP include:

- an executive summary of the MANPRINT program
- a description of the proposed system, with the acquisition strategy, agencies involved and any existing guidance also described
- a description of the MANPRINT strategy including the objectives, data source availability, and planned MANPRINT analyses
- any issues or areas of concern which have been identified
- the tabs, which include lists of data sources, MANPRINT milestones, MANPRINT task descriptions, questions to be resolved, and organizations with which the SMMP must be coordinated.

Although the regulation requiring the SMMP is new, guidance is available through the SMMP Procedural Guide, published by the Soldier Support Center - National Capital Region. It is expected that as more experience is gained by those who prepare the SMMP, the SMMPs will increasingly address all key issues in the MANPRINT domains and provide a useful management plan to control MANPRINT-related factors such as OWL.

Several sections of the SMMP provide opportunities to address OWL concerns early and throughout the MAP. In particular, the MANPRINT strategy section (Section 3) should identify any OWL-related objectives and describe the OWL analysis part of the plan. The concerns section (Section 4) is an appropriate place to discuss any identified issues. These concerns should be monitored throughout the MAP. Further, the questions to be resolved (in Tab D) are questions that need to be answered to address the identified concerns.

These questions should be detailed and specific. In some ways, development of the detailed questions will lead to the analyses necessary to obtain sufficient information to answer the questions.

Sections 3 and 4 and Tab D of the SMMP are each to be organized by the six MANPRINT domains. However, for each of these sections, another "other" category is to be used for strategies, concerns, and questions that are not covered by or linked to any individual MANPRINT domain, or that have some other MANPRINT impact. If OWL is not uniquely related to just one MANPRINT domain, as will often be the case, the OWL issues can be listed with more than one MANPRINT domain as well as with the "other" category.

Other parts of the SMMP also provide an opportunity to incorporate OWL into the acquisition process. Tab A of the SMMP is identified as the place to list all potential MANPRINT-relevant data sources and should include those sources relevant to OWL. A description of the tasks or activities required to support MANPRINT efforts are to be presented in Tab C. These descriptions include the rationale, resources needed, time to complete, and responsible agencies for each task required as part of the MANPRINT analysis for a system. Tasks in support of OWL analyses should also be listed in Tab C.

If an awareness of, and sensitivity to OWL issues is developed by those preparing the SMMP, the plan will provide the means to surface broad concerns about workload as well as the specific questions that need to be investigated to adequately address the stated concerns. The identification of a predecessor system and data list will directly affect the types of OWL predictive or evaluative assessments that can be conducted. Similarly, the existence of a predecessor system and database will affect the timeliness with which such assessments can be performed. The degree to which data sources are well-documented and available will facilitate their usefulness.

Any key OWL issues or concerns should also be included in the executive summary of the SMMP which presents an overview of the MANPRINT program. The program summary will be the portion most often read by decision makers at all levels in the system acquisition process and will give visibility to the key issues. The status of key issues can be monitored and managed as the SMMP is continually updated with current information.

Another aspect of the SMMP that is of key importance for addressing OWL issues and concerns is the role of the MANPRINT joint working group (MJWG). Although the SMMP is generally the responsibility of the combat developer, it is to be developed in conjunction with the materiel developer. The MJWG is the group of people who are to work together to create the SMMP. The MJWG includes representatives from the combat developer, the materiel developer, and other organizations that are involved with the development or deployment of a new or improved system. The SMMP should consequently have inputs from all interested organizations; they all should play a part in generating the lists of concerns, questions, and tasks to be accomplished.

Summary

The purpose of this pamphlet is to present information on how to address operator workload issues and concerns during the system acquisition process. The position taken is that a system operator has a limited capability to perform. Therefore, the performance limitations of the human component of the system must influence the requirements and design of the system as does the limited capabilities of hardware components.

Three specific types of actions required to address the possible impact of exceeding OWL limits are presented and discussed. There is first the need to define OWL issues and concerns, typically by way of comparison with existing comparable systems and system components. General statements of broad concern should be analyzed into series of detailed and specific questions that, if not satisfactorily resolved, become constraints on the system development process.

Second, an appropriate OWL assessment program will have to be developed. The process for assessing the OWL associated with a given system acquisition program should incorporate batteries of OWL assessment techniques. The particular techniques which make up the battery will vary over the life cycle of the acquisition program; analytical methods will be used to predict OWL early in the system development process, and empirical techniques will be used as hardware becomes available for evaluation later in the acquisition cycle.

The third type of action is to integrate all OWL-related activities into the system acquisition program, beginning with the earliest conceptual stages of the process. It is recommended that the Army MANPRINT initiative be the vehicle for integrating OWL considerations into the acquisition program. Operator workload issues can be related to the six MANPRINT domains, and the mechanism for integrating OWL-related activities into the system acquisition program exists in the SMMP.

REFERENCES

Government Documents

Headquarters, Department of the Army. Washington, D.C.

Army Regulation (AR):

70-1: Systems Acquisition Policy and Procedures. November 1988

70-8: Personnel Performance and Training Program (PPTP). October 1976

70-10: Test and Evaluation During Development and Acquisition of Materiel. August 1975

71-2: Basis Of Issue Plans (BOIP) Qualitative and Quantitative Personnel Requirements Information (QQPRI). August 1983

71-3: User Testing. March 1970

71-9: Materiel Objectives and Requirements. February 1987

350-35: Army Modernization Training. September 1984

570-2: Manpower Requirements Criteria (MARC) -- Tables of Organization and Equipment. July 1989

602-1: Human Factors Engineering Program. February 1983

602-2: Manpower and Personnel Integration (MANPRINT) in the Materiel Acquisition Process. May 1987

700-127: Integrated Logistic Support. April 1988

Headquarters, Department of Defense (DOD). Washington, D.C.

DOD Directive (DODD) 5000.1: Major and Nonmajor Defense Acquisition Program. September 1987

DODD 5000.53: Manpower, Personnel, Training and Safety (MPTS) in the Defense System Acquisition Process. December 1988

DOD Instruction (DODI) 5000.2: Defense Acquisition Program Procedures. September 1987

MIL-H-46855B: Human Engineering Requirements for Military Systems, Equipment and Facilities. January 1989

MIL-STD-1388-1: Military Standard Logistic Support Analysis. April 1983

MIL-STD-1388-2: Military Standard DOD Requirements for a Logistic Support Analysis Record. February 1986

MIL-STD-1472C: Human Engineering Design Criteria for Military Systems, Equipment and Facilities. March 1989

Naval Publication and Forms Center, 5801 Tabor Avenue, Philadelphia, PA.

DI-H-7052: Human Engineering Dynamic Simulation Plan

DI-H-7056: Human Engineering Design Approach Document - Operator

DI-H-7057: Human Engineering Design Approach Document - Maintainer

U.S. Army Soldier Support Center - National Capital Region (SSC- NCR), [name changed to U.S. Army Personnel Integration Command (USAPIC)], 200 Stovall Street, Alexandria, VA. (ATTN: ATNC-NMF-B).

The System MANPRINT Management Plan (SMMP) Procedure Guide. 1987

U.S. Army War College. Carlisle Barracks, PA. (ATTN: Department of Command, Leadership, and Management).

Army Command and Management: Theory and Practice. 1989

Technical Publications

Casper, P. A., Schively, R. J., & Hart, S. G. (1986). Workload consultant: A microprocessor-based system for selecting workload assessment procedures. Proceedings of the IEEE Conference on Systems, Man, and Cybernetics.Piscataway, N.J.: IEEE Service Center.

Casper, P. A., Schively, R. J., & Hart, S. G. (1987). Decision support for workload assessment: Introducing WC FIELDE. Proceedings of the Human Factors Society 31st Annual Meeting. Santa Monica, CA: Human Factors Society.

Gopher, D., & Donchin, E. (1986). Workload: An examination of the concept. In K. R. Boff, L. Kaufman, & J. Thomas (Eds.), Handbook of perception and human performance: Vol. II. Cognitive processes and performance. N.Y.: John Wiley & Sons.

Harris, R. M., Hill, S. G., Sams, M. R., & Christ, R. E. (1990). Handbook for operating the OWLKNEST technology (HOOT) (Technical Report 2075-5C). Willow Grove, PA: Analytics, Inc.

Hill, S. G., & Harris, R. M. (1989) OWLKNEST: A knowledge- based expert system for selecting operator workload techniques. In A. Genaidy and W. Karwowski (Eds.), Computer-aided design: Applications in ergonomics and safety. London: Taylor and Francis.

Lysaght, R. J., Hill, S. G., Dick, A. O., Plamondon, B. D., Wherry, R. J., Jr., Zaklad, A. L., & Bittner, A. C., Jr. (1989). Operator workload: Comprehensive review and evaluation of operator workload methodologies (Technical Report No. 851). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences. (AD A212 879)

O'Donnell, R. D., & Eggemeier, T. (1986). Workload assessment methodology. In K. R. Boff, L. Kaufman, & J. Thomas (Eds.), Handbook of perception and human performance. Vol. II. Cognitive processes and performance. N.Y.: John Wiley & Sons.

GLOSSARY OF ACRONYMS

AAE	Army Acquisition Executive
AMC	Army Materiel Command
AR	Army Regulation
ARI	Army Research Institute for the Behavioral and Social Sciences
ASA	Assistant Secretary of the Army
ASAP	Army Streamline Acquisition Process
ASVAB	Armed Services Vocational Aptitude Battery
BOIP	Basis of Issue Plans
C2E	Continuous Comprehensive Evaluation
CBTDEV	Combat Developer
CFP	Concept Formulation Package
DA	Department of the Army
DID	Data Item Description
DOD	Department of Defense
DODD	Department of Defense Directive
DODI	Department of Defense Instruction
HFE	Human Factors Engineering
ILS	Integrated Logistic System
JMSNS	Justification for Major System Need Statement
LEA	Logistic Evaluation Agency
LSA	Logistic Support Analysis
LSAR	Logistic Support Analysis Record
MAA	Mission Area Analysis
MADP	Mission Area Development Plan
MANPRINT	Manpower and Personnel Integration
MAP	Materiel Acquisition Process
MARC	Manpower Requirements Criteria
MATDEV	Materiel Developer
MJWG	MANPRINT Joint Working Group
MOS	Military Occupational Specialty
MPT	Manpower Personnel and Training
MPTS	Manpower Personnel Training and Safety

NASA	National Aeronautics and Space Administration
NDI	Non-Developmental Item
NET	New Equipment Training
O&O PLAN	Operational and Organizational Plan
OT	Operational Test
OTEA	Operational Test and Evaluation Agency
OWL	Operator Workload
OWLKNEST	Operator Workload Knowledge-based Expert System Tool
P3I	Pre-Planned Product Improvement
PEO	Program Executive Officer
PM	Program (or Project) Manager
QQPRI	Qualitative and Quantitative Personnel Requirements Information
ROC	Required Operational Capability
SCP	System Concept Paper
SMMP	System MANPRINT Management Plan
TOE	Table of Organization and Equipment
TRADOC	Training and Doctrine Command
TT	Technical Test
WC FIELDE	Workload Consutant for Field Evaluations