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An Initial Analytic Process Model for Systems Measurement: Extensions of the Systems Taxonomy Model

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This report briefly summarizes work completed under Task 3 of ~~the subject~~ a contract. It describes several accomplishments including an evaluation of the state of the art of ~~manned~~ systems measurement, the identification of research requirements on the basis of the literature review, the application of the most recent project model to the Infantry Fighting Vehicle, the resulting revision of the overall conceptual process model for performance measurement, and an initial look at the potential for specifying codification strategies to be used in future model development efforts.

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I. INTRODUCTION

This report was prepared under the overall contract for the "Study of Effectiveness of Infantry Systems: TEA, CTEA, and Human Factors in Systems Development and Fielding" (MDA903-80-C-0345). Dunlap and Associates, Inc., was responsible for Task 3 (System Development and Evaluation Technology) of that contract, under subcontract (No. 05628) to the Mellonics Systems Development Division of Litton Systems, Inc. The principal end product of Task 3 was an improved model for the overall process of measuring the performance and effectiveness of existing human-machine systems. It was not expected that this would be a fully developed overall process model; such full development requires research that is beyond the present scope of work. However, the project has yielded initial developments required to advance the measurement state of the art, and has provided a foundation for further development in the future.

The rationale behind the work on this project rests with the problem that testers, analysts and researchers too often use an incomplete or inappropriate set of human performance measures in evaluating human-machine systems. Those are usually known measures often selected without adequate consideration of the system context, which may not help clearly assess system performance and may not provide adequate answers to the essential questions about system effectiveness. Because there is no verified analytic process for deriving the optimal measures of a system's performance or effectiveness, true assessment needs are difficult to define and the process is relatively haphazard. The typical solution is to measure the easy and accessible system points, but not necessarily those that should be addressed. Without having more systematic procedures, people measure what can be counted or observed (e.g., number of troops trained). They design written tests to assess facts rather than understanding, and use criteria such as end-of-course tests rather than on-the-job performance. Rarely do people know the relationship between test performance and job performance, or between soldier job performance and unit effectiveness. The results of those inadequacies of the measurement determination process are the wasting of valuable resources (time, effort, talent, money), the failure to provide adequate answers to effectiveness questions, and the relegation to obscurity of the elusive questions regarding human contributions to system performance. A better method is required to decide what should be measured and how.

This project was conceived to produce more adequate and efficient processes for measuring systems' effectiveness than now exist. A first step in this production is described in this report. It is an initial model of the conceptual and analytic procedures necessary for the determination and development of fully adequate systems' effectiveness measurement/testing. A major part of the model is the Systems Taxonomy Model (STM) originally conceived by Finley et al. (1975, 1976).* This report describes the evolutionary revision of that STM (in part

*Finley, D.L., Muckler, F.A., Gainer, C.A. and Obermayer, R.W. An Analysis and Evaluation Methodology for Command and Control: Final Technical Report. Northridge, CA: Manned Systems Sciences, Inc., November 1975. NTIS No. AD A023871.
Finley, D.L. and Muckler, F.A. Human Factors Research and the Development of a Manned Systems Applications Science: The System Sampling Problem and a Solution. Northridge, CA: Manned Systems Sciences, Inc., July 1976. NTIS No. AD A029417.

through application of the STM to several systems of varying complexity); the initial thinking about the total model and the relevance of the STM to the model; and considerations of the nature and extent of future research required for further development of these concepts and the eventual production of usable procedures for analytic application. A model of the overall process of measuring the performance/effectiveness of human-machine systems must address the following, among other issues:

- The identification of measures of performance/effectiveness that are relevant to the system under study and to the measurement purpose at hand.
- The specification of criteria or standards of performance/effectiveness to be used to assess the outcome of the measures.
- The development of a comprehensive test plan in which the measures are to be employed.
- The implementation of the test plan, including in particular the collection of all appropriate data.
- Reduction, analysis and interpretation of the data.

The initial issue in this overall conceptualization of the measurement process ("identification of measures") is the purview or technical scope of the STM. Basically, the STM is conceived to be a set of procedures for identifying the system populations (taxonomies) to which a system of interest belongs, and for organizing those populations in a way that provides information relevant to the system's measurement. The role of system taxonomization in the human-machine system measurement process derives from the following fundamental observations, or postulates:

1. In any system measurement effort, the system itself must be an important source (really, the key source) of measurement variables. System measurement efforts often have failed or been deficient because they focused exclusively on components studied out of the system context.

2. Systems exist as viable entities that form populations. That is, any system can be grouped with other systems on the basis of some attribute that they share or have in common.

3. Important variables for measurement can be gleaned from a knowledge of the populations to which the system under study belongs. By identifying the populations, and their organizational bases, the measurement analyst can more easily discern the system attributes of concern to the research at hand. Also, organized sets of system populations can guide the analyst to relevant segments of the published literature, to facilitate extraction of information concerning measurement methods and results derived from similar systems.

4. The system populations (or taxonomies) to which the system of interest belongs are (in the abstract) the measures of performance/effectiveness. They tell the analyst exactly what the system must possess, or do, or produce in order to accomplish the mission being studied. That is, they tell the analyst what must be measured.

The key to using taxonomization as the means of identifying the appropriate measures is the ability to isolate the system populations that truly are relevant to the particular measurement application. Any system can be thought of as belonging to a vast array of different populations, depending on the attributes or characteristics being considered. It is possible that there may be an infinite number of population memberships for any given system. Assuming that the relevant measurement issues comprise a finite, manageable set, the problem becomes one of being able to extract the corresponding finite, manageable collection of taxonomies from the vast array of possible memberships. The STM was first proposed as a tool for solving that problem.

In the original research carried out by Finley and her colleagues, system taxonomy modeling was viewed from the perspective of the types of measures suited to the various research questions systems analysts face and to the various levels of descriptive detail that characterize a system at any stage in its life-cycle. What emerged was a structure that appeared to encompass satisfactorily all taxonomies that might be relevant to a particular measurement application of a particular system. However, the original research produced few if any guidelines for applying the taxonomization process to an actual system. The present project continues the STM development effort to the point where its utility for measures generation could be tested, and where it (the STM) can be incorporated into a model of the overall analytic process.

The scope of this effort, then, was to develop further, to apply, and then to extend the STM. The specific activities undertaken included:

- A review of the original research into the STM concept, both to acquire fuller awareness of its fundamental principles and postulates and to identify specific needs for further development.

- A review and analysis of all pertinent additional literature to assure full awareness and consideration of all relevant data.

- A "first revision" of the STM, specifically to extend the concept to the point where it could be applied to generate relevant taxonomies for typical systems of interest.

- A trial application of the revised STM to generate taxonomies and a measures hierarchy for a typical military human-machine system (the Infantry Fighting Vehicle) in a typical applications context.

- A "final revision" of the STM reflecting the findings and conclusions of the trial application. Detailed utilization procedures were to be prepared for the "final revision" model.

- Development of the initial form of the overall analytic process model for design of system's effectiveness measurement procedures and techniques.

- Examination of the requirements for research and development necessary to the further extension of the initial model and the development of the requisite procedures and techniques.

The report documents the above-listed activities and their outcomes in the context of the developmental framework that guided this project. Basic concepts dealing with system measurement evolved during the project. Chief among these were notions regarding the dimensions and taxa of human-machine system performance, and notions regarding the implications of those dimensions and taxa for the measurement of system performance and effectiveness. The authors have attempted to trace the evolution of their thinking, in order to communicate more effectively the logic and rationale behind the model that ultimately emerged. Thus, the report is organized around a historical perspective.

II. EXTENSIONS OF THE STM

A. Initial STM Concepts and Definitions

Measurement of performance and effectiveness has been going on for a long time, and many pure and applied research efforts for assessing manned systems capabilities and limitations have been reported. Widely accepted and frequently used analytic techniques abound. The initial work on manned system measurement and associated taxonomies by Finley and her colleagues indicated that certain prerequisites exist for including "system" factors in manned system performance measurement. They are:

- Recognition of systems as viable entities in and of themselves.
- Development of conceptual tools for the purpose of:
  - Grouping systems into populations.
  - Defining these populations.
  - Placing them into a context with other populations.

In all cases, the basic purpose of a taxonomy is to supply knowledge that is specifically relevant to the particular analytic application at hand. Thus, each system taxonomy is unique to the particular system and to the particular context and purposes in and for which the measurement process is to be applied. What Finley et al. sought was a systematic way of generating such taxonomies for any given system and measurement purpose. Development of the STM by those researchers and in the current project was intended to help meet that need. Within an overall conceptual process model for evaluation, the STM is a tool that will support the taxonomy development process for manned system studies. The STM development was to provide a mechanism for identifying taxonomies (associated with some particular human-machine system) that would supply information bearing on the measurement of that system's performance and/or effectiveness. Knowledge of the human-machine system populations to which a particular system belongs (or with which it interacts, in a fashion clarified below) should aid the performance/effectiveness measurement analyst in at least two ways:

- First, it should point out the factors or characteristics of the system that must be addressed in the measures and/or measurement procedures that ultimately are selected. That is, system populations can be formed on the basis of any and all of the following: the kind of system each population member is supposed to be; the kind of mission each member is supposed to be able to do; the circumstances, conditions, and constraints under which each member is supposed to work; the specific requirements and criteria each member is supposed to satisfy; etc. Each such population immediately suggests measurement issues, such as: Is the system what it is supposed to be? Can it do what it should? Will it work where it is supposed to?
- Second, this knowledge of the populations associated with a particular human-machine system should provide a "road map"

to the relevant segments of the system measurement literature. If the populations are well defined, the analyst should be able to extract information from previous research on systems similar to the one of interest—similar in the sense that they share a population membership in common. It can plausibly be argued that it is this aspect of system taxonomization that ultimately may prove most beneficial, in that it may impose order on the vast body of system measurement literature, and allow findings gained in the study of one system to be extended to the studies of others.

The Original STM Concept: One Dimension (System Description Levels) Plus Implications

The STM was originally viewed as a systematic method or mechanism for identifying which of a system's many taxa (population memberships) are relevant to a specific measurement of that system's performance/effectiveness. Such a model would be tantamount to a mechanism for specifying the measures for that specific measurement application. The concept was organized around three basic factors:

1. Measurement Level Definitions—the two general measurement levels are nominal and relative. The former encompasses measurement categories that are not ordered (in the mathematical or comparative sense), e.g., "apples" and "oranges." The latter pertains to ordered categories, including the ordinal, interval, and ratio classifications familiar from elementary statistics. One of the fundamental postulates (previously cited) asserts that the taxonomies associated with a given system are abstractions of measures of that system's performance/effectiveness. The implication is that some taxonomies are abstractions of nominal measures; others, of relative measures. Since the two general levels of measurement often are suited to different measurement purposes, it is clear that the STM's structure should provide for separation or selective identification of a system's nominal and relative taxonomies.

2. Types of Research Questions—every specific system measurement application has its own unique set of specific research questions or issues. Generally, however, such questions fall into two types, viz., fundamental research or applied research. Fundamental research issues typically are concerned more with generic classes of systems than with a particular system. Applied research issues often delve into the specific operational characteristics of a particular system, thus examining operations on a microscopic level. The kinds of measures appropriate to these two different research perspectives are likely also to differ. The STM should allow the system's taxa to be identified and organized in a way that reflects the kinds of research questions at hand.

3. Levels of System Description—this factor is closely associated with the previous two. The concept of interest here is that any system can be described on several levels of increasing detail. First, it

can be described as an indivisible, macroscopic entity, or "black box"; this level of description can be thought of as focusing on the system's basic objectives. Taxa that would be identified on that level of description would be expected to generate nominal measures of performance/effectiveness, and would tend to be particularly well suited to fundamental research issues. Secondly, the system can be described in terms of how it can be applied, i.e., its functional purposes. This level of description probably would produce taxonomies suited to both major types of research questions and would generate both nominal and relative measures. Thirdly, a system can be described in terms of how it can achieve its purposes, i.e., in terms of the characteristics of its operations. This level of description would tend to correspond to relative measurement, and to applied research issues.

The original structure of the STM, as organized around the factors discussed above, is depicted in Figure 1. As shown, the objectives level of system description associates exclusively with nominal measurement. The characteristics level associates exclusively with relative measures. The functional purposes level deals with both levels of measurement.

The review of the fundamental concepts underlying the STM led to the conclusion that the structure illustrated in Figure 1 implies a logical basis for organizing a system's taxa that are relevant to its measurement. However, it was also apparent that substantial further development was needed before the model could actually be applied to generate measures hierarchies for specific systems and specific measurement purposes. As points of departure for that further development, it was noted that:

- The STM must be system-oriented. Its structure must reflect the fact that it is intended to be applied to individual systems, with their own features, attributes, operations, reasons-for-being, and all the other qualities that, collectively, make a particular system whatever it happens to be. All system measurement should proceed strictly in the context of the system itself. The STM's original structure did not explicitly reflect the elements that make up the system context.

- The STM is not an end in itself. It is part of the overall model of human-machine system measurement that is the ultimate focal point of this project. Hence, the STM's structure should explicitly reflect those stages of the total measurement process to which it applies.

Preliminary Definitions of the Second Dimension (Process Stages)

Preparation for the "first revision" of the STM thus required the enumeration of the stages of the overall measurement process, in terms firmly imbedded in the context of the system being studied. Then, it was necessary to identify which stages fell within the purview of the STM, and to extend the model's structure to incorporate those stages explicitly. Accordingly, one of the project staff's first activities was to construct a preliminary outline of the components

	MEASUREMENT LEVELS	SYSTEM TAXONOMIC LEVELS	EXAMPLES OF POSSIBLE TAXONOMIC CATEGORIES & DIMENSIONS
LEVEL ONE	Nominal Measurement	SYSTEM OBJECTIVES	• Production • Supply • Navigation • Air Traffic Control • Health & Welfare • Transportation • Maintenance • Weapons • Surveillance • Etc.
LEVEL TWO	Nominal ⇧ - - - - - - - ⇩ Relative	SYSTEM FUNCTIONAL FURPOSES	Nominal • Indirect command/control/guidance operations • Relatively direct control/navigation operations • Maintenance operations • Data or materials processing - - - - - - - Relative • Command • Control • Information • Data
LEVEL THREE	Relative Measurement (Ordinal, Interval and Ratio)	STRUCTURAL CHARACTERISTICS	• Organization and layout • Size • Level of automation • Implementation capabilities
		OPERATOR/EQUIPMENT CHARACTERISTICS	• Human skills, equipment conditions • Human abilities & IQs, equipment capabilities • Values • Needs
		OPERATING CHARACTERISTICS	• Inputs to operator • Operator processing • Operator outputs • Units being dealt with by system • Environment • Feedback
		SUPPORT REQUIREMENTS CHARACTERISTICS	• Materials (including people) • Maintenance (including people)

From: Finley & Muckler (1976) and Finley et al. (1975)

Figure 1. A General Systems Taxonomy Model (Initial Status)

of the measurement process. Figure 2 depicts those components, each of which is described briefly below.

Define the System

If the system is to serve as the key source of variables for its own measurement, it seems appropriate to begin the measurement process by specifying exactly what that system is supposed to be. The analyst ought to be aware of precisely what kind of system is involved in the research at hand.

Define the Mission

In any given measurement application, one is concerned with determining the performance/effectiveness of some particular system in carrying out some particular mission (or set of missions). Thus, it seems appropriate to include a mission-specification step explicitly in the measurement process outline. The analyst needs to know exactly what kinds of jobs the system is supposed to do, since the ultimate purpose of the measurement is to determine how well or how effectively the system can do those jobs.

Specify the Environment

The question, "Can the system do its job?", implicitly includes the qualifying phrase, "at the times and places where it is supposed to do its job". Performance/effectiveness measurement ultimately must reflect how well the system does its jobs under real-world conditions. The analyst needs to know exactly what those conditions will be in order to plan and implement the measurement process properly.

Specify the General Constraints

A special case of the real-world conditions that surround a system and its missions is the set of limitations or constraints imposed on how the system is to do its job. Such imposed conditions arise from conscious, human intervention, in recognition of tactical doctrine, safety and health protection, economic necessities, and various other factors. The analyst also needs to know exactly what these conditions are for proper planning of the measurement application.

Identify the Ultimate Performance Requirements

A major determinant (if not the major determinant) of a system's performance/effectiveness is its ability to produce the output expected of it. The measurement analyst clearly needs to know exactly what goods, services, or other products are supposed to result from the successful performance of the system's jobs.

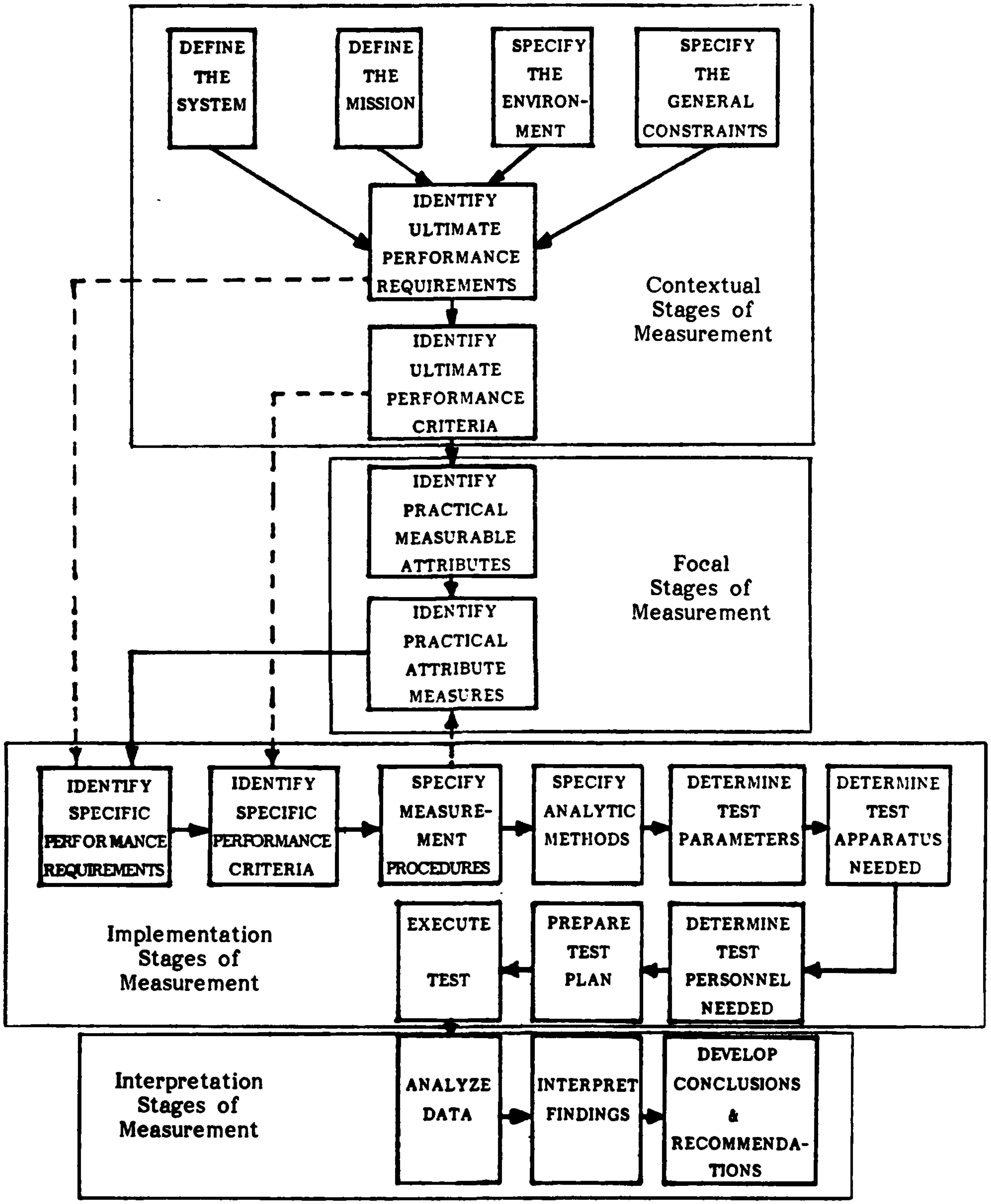


Figure 2. Initial Conceptual Outline of Stages in the Overall Measurement Process

Identify the Ultimate Performance Criteria

It isn't enough that a system manages to deliver the kind of product expected of it. The product must meet certain standards of acceptance to satisfy the needs of its user. These standards, or criteria, might pertain both to the quality and quantity of the products delivered, to the timeliness of the delivery, to the cost to the user, and to various other attributes. The analyst needs to know exactly what these criteria are in order to provide a full assessment of system performance/effectiveness.

The six stages listed above can be grouped under the label, "contextual stages." They reflect the system-as-source-of-variables. It is precisely this segment of the overall measurement process that was taken to constitute the purview of the STM.

Identify Practical Measurable Attributes

Once the analyst knows what the system is supposed to do and produce, he or she must identify concrete, observable events, effects, phenomena, etc., that can be used to determine whether or not the system's jobs have been done and the intended results produced. These events, effects, phenomena, etc., are things-that-can-be-measured, and whose presence, size, weight, number, or whatever indicates how well the system has done its job.

Identify Practical Attribute Measures

The analyst needs explicitly to determine exactly what features of those events, effects, phenomena, etc., will be measured to assess system performance/effectiveness. Some examples of such features were given above, i.e., the presence of some phenomenon, the size of some effect, the number of events of some type that occur, the weight of some object that is produced. Other common examples of measurable features might include the ratio of frequency of occurrence of two kinds of events, the time at which some event takes place, the speed of some moving object, etc. Any such feature that directly (or inversely) relates to system performance or effectiveness could serve as a "yardstick," or measure. Identification of measures that are both appropriate and practical is one of the most important steps in the total measurement process. Often, it is a step that must be pursued iteratively, about which more will be said subsequently.

The preceding two stages are called the "focal stages" of the overall measurement process. That is, the measurement analyst focuses on the attributes and their measures as the prime ingredients of the assessment of system performance. These two stages can also be viewed as the desired product of the system taxonomization process: It is the set of attributes and measures that the STM ultimately is to aid the analyst in specifying.

Identify Specific Performance Requirements

Once the measures have been selected (at least tentatively) the analyst must translate the general expression of the system's intended products, goods, services, etc. (i.e., the "ultimate performance requirements"), into terms keyed to the measures. This is the specification of performance requirements in measurable terms. For example, the human-machine system consisting of a bicycle and its rider must produce personal transportation of the rider from some point ("A") to another point ("B").

Identify Specific Performance Criteria

Similarly, the analyst must translate the general expression of product adequacy (i.e., the "ultimate performance criteria, or standards") into terms keyed to the measures. This is the specification of performance criteria in measurable terms.

Specify Measurement Procedures

The technical and procedural details concerning how the measures will be applied need to be established. Here the analyst must determine exactly how the data needed to generate each measure will be collected, and how quality control over the collection process will be maintained. At this point, it is very possible that it may be determined that the data needed to provide some previously selected measure simply cannot be collected, at least not with sufficient quality or at tolerable cost. If so, the analyst must delete that measure from his or her plans and select some alternate "yardstick" for that particular aspect of performance/effectiveness. Thus, as was suggested above, the measures selection process may be iterative, and this procedural specification step plays a key role in that regard.

Specify Analytic Methods

Before any data are collected, the analyst must determine exactly what will be done with those data. This includes specification of the statistical tests to be employed, the combinatorial procedures to be used, the level of precision desired, etc. From these, in turn, the analyst must determine the scope of the measurement application, e.g., sample size, replications, etc.

Determine Test Parameters

At this point the analyst may determine what conditions will be varied for test purposes, what will be held fixed, the sequence in which variables will be manipulated, how the data will be grouped into class intervals, etc.

Determine Test Apparatus Needed

The analyst must specify exactly what apparatus (hardware and software) will be used in the measurement application. This includes a specification of the kinds of data such apparatus will output, the format and media of the data, and any apparatus support requirements that may exist.

Determine Test Personnel Needed

Similarly, the analyst must specify exactly what types of people will be involved in the measurement application. This includes both the people who will conduct the test (as administrators, analysts, data collectors, logistic support, etc.) as well as the people who will operate the system during testing (test subjects). The analyst must specify the numbers of people needed, the qualifications they must have, relevant demographic or other characteristics they must have, pre-test training they are to receive, etc.

Prepare Test Plan

This step is a summation and formal recording of the seven immediately preceding steps. The plan documents the specific performance requirements and criteria, the measurement and analytic procedures (including the final iteration on the measures selection), test parameters, test apparatus, and test personnel for review, reconsideration, and possible revision.

Execute Test

At this point, the test plan is implemented, the measures finally are taken, all data are collected, and the stage is set for conclusions to be drawn concerning the system's performance/effectiveness.

The preceding nine stages are called the "planning and implementation stages." It is at this segment of the overall measurement process that the analyst faces the practical considerations that permit the measures of performance/effectiveness to be applied meaningfully in the context of a real-world test.

Analyze Data

In accordance with the analytic procedures defined in the test plan, the analyst must reduce, combine, and manipulate the data to produce the quantitative and qualitative bases for assessing the system's performance/effectiveness.

Interpret Findings

Based on the outcomes of the measurements and the statistical tests, the analyst must extract a comprehensive, quantitative assessment of the system's performance/effectiveness in the context of the research issues at hand.

Develop Conclusions and Recommendations

As the final step or component of the measurement process, the analyst must apply his or her findings to answer the questions relevant to the measurement application. Such questions might include: Is the system feasible? Is it cost-effective? Is it, overall, better or worse than some other, competing system? How can specific deficiencies be corrected?

These last three stages are called the "interpretation stages" of the overall measurement process. It is here, finally, that the measures derived from the system's taxonomies produce the desired assessment of the system's performance/ effectiveness.

The twenty steps discussed above and depicted in Figure 2 were considered to provide a reasonably detailed and comprehensive outline of the overall measurement process, at least for the purposes of organizing the findings to be gleaned from the review of the measurement applications literature. They obviously do not constitute the only valid representation of the overall process of human-machine system measurement. Other researchers likely would use different (but equally correct) terminology to describe this total process, and probably would organize the stages differently to suit the particular needs of their own research pursuits. Let it suffice to say that this twenty-stage schema is one valid model for the process and, most importantly, it is a model that delineates the role of system taxonomies within that overall process. Clearly, it was not considered to be a sufficiently well defined specification of the process to permit construction of an overall Conceptual Process Model (CPM). Indeed, it was not expected that the research effort that was about to begin would accomplish much more than to improve the specificity of the process outline to the point where one could start to construct major segments of the overall model. Now that the first year's research effort has been completed, it is evident that the preliminary process outline contained numerous ambiguities, and some room for improvement. Many of these have now been clarified. Other improvements will be made in the near future. Details are provided in subsequent sections of this report. To conclude this section, suffice it to note that what was expected of the preliminary process outline was that it possess sufficient validity to serve as an efficient point of departure for the research effort. That expectation was met.

B. First Revision of the STM (See Ref.*)

Some Further Definitions of the Second Dimension

Based upon the review of the original STM concept, and upon the enumeration of the overall measurement process stages, it was concluded that the STM could be represented as a 3-by-6 matrix. The "cells" of that matrix correspond to the interactions among each of the three levels of system description and each of the first six stages (the contextual stages) of the overall measurement process. Figure 3 depicts this matrix structure. That structure was taken as the point of departure for the STM revision effort. The immediate objective was to develop procedural guidelines for identifying the taxonomies belonging to each "cell" of the STM; that would constitute the "first revision" of the STM.

*Bloom, R.F., Oates, J.F. and Hamilton, J.W. , System Development and Evaluation Technology: Systems Taxonomy Model—First Revision. Darien, CT: Dunlap and Associates, Inc., September 1980.

Levels of System Description	Contextual Stages of Measurement					
	System Definition	Mission Definition	Environment Specification	General Constraints	Performance Requirements	Performance Criteria
Objectives						
Functional Purposes						
Characteristics						

Figure 3. Structure of STM Taken as Point of Departure for "First Revision"

A basic premise of the first revision of the STM is that the measurement-relevant taxonomies for any human-machine system are those defined by the contextual stages of the overall measurement process. In other words, the STM is to help insure that the system serves as a source of variables for its own performance measurement by aiding the analyst in determining the population categories to which the system belongs by virtue of the following six aspects of the system:

- Basic System Definition
- Mission Definition
- Environment Specification
- General Constraints Specifications
- Ultimate Performance Requirements
- Ultimate Performance Criteria

Formation of Relevant Taxonomies

Two preliminary questions are involved in any instance where system taxonomies are to be generated in support of a performance measurement requirement:

1. What are the measurement purposes?

   Why is this particular performance measurement effort being undertaken and what are the fundamental issues involved? Is it a basic research effort or is it strictly a pragmatic evaluation of one specific system? Do the issues of interest extend to all aspects of the system, and all of its objectives and capabilities, or are they restricted to only some of the system's performance requirements? The measurement purposes may range from the very restricted to the totally comprehensive, and will affect how many of the system's myriad of population categories really are relevant in the specific instance at hand.

2. What levels of system description are pertinent?

   The three levels of system description are the Objectives Level, the Functional Purposes Level, and the Characteristics Level. There is a logical correspondence among these levels and the stage of a system's development. There is also a correspondence between each level and the type of performance measures it tends to produce (nominal, relative or "mixed") and thus between each level and the kinds of issues for which it is appropriate (qualitative versus quantitative aspects of system performance). The number and kinds of system population categories that will prove to be relevant in any particular measurement effort thus will depend heavily on whether only one, or two, or all three of the levels of system description are to be involved.

With the above questions in mind, the first STM revision developed general guidelines for producing sets of taxonomies.

A Model Applications Approach

An iterative approach was adopted to identify taxonomization guidelines and any further needs for revising the STM's structure. Conceptually simple systems (presumably having simple sets of taxonomies associated with them) would be studied. As their taxonomies were identified, the staff would seek to extract principles for organizing those taxonomies. These principles would be written as rudimentary guidelines, and used to identify the taxonomies of slightly more complex systems, which in turn would disclose additional insight for clarifying the guidelines. The process would continue until the guidelines achieved a degree of specificity deemed sufficient for application to a typical military human-machine system of reasonable complexity (e.g., the Infantry Fighting Vehicle).

Following the approach just outlined, attempts were made (by several staff members, working independently) to identify the populations associated with such very simple systems as:

- the bicycle/rider
- the typewriter/typist
- the photocopier/operator
- the radio receiver/operator-listener

Complete sets of taxonomies were not sought in all cases, but only a sufficient number and variety to identify organizing principles within the eighteen "cells" of the STM. What emerged was a set of questions, one per cell, that appeared to express adequately the interaction between each level of system description and each contextual stage of the measurement process. These preliminary organizing principles are arrayed in the basic matrix format in Figure 4.

The preliminary set of principles or guidelines, although expressed in very abstract terms, is sufficiently clear to permit some fundamental features of the STM to emerge. First, the substance or focus of measurement consists of what the system is supposed to be (system definition), what job it is supposed to do (mission definition), and what output it is supposed to produce (performance requirements and criteria). Second, the system's performance is to be measured within the context of its surrounding (natural) environment and also within the context of any constraints that are imposed upon it during the particular measurement application at hand. Third, the STM "cells" and their guidelines are not totally independent, rather, the three levels of system description are strongly linked in a general-to-specific fashion. Thus, the guidelines on the Characteristics Level of description refer back to the Functional Purposes Level guidelines, which in turn refer back to the Objectives Level. These basic features have remained unchanged through all subsequent revisions and clarifications of the STM.

A Third Dimension (the System Hierarchical Structure) as a Source of Measurement Variables.

One other very important finding emerged from the simple system taxonomization exercises. It became evident that it is impossible to identify all populations relevant to the measurement of a particular system by examining that system in isolation. Many systems actually are parts of larger systems, and carry out their missions to serve the ends of the larger systems. Similarly, many systems themselves contain smaller systems whose performances are major determinants of the

	System Definition	Mission Definition	Environment Specification	General Constraints	Performance Requirements	Performance Criteria
Objectives	What is this system supposed to be?	What job is this system supposed to do?	Under what circumstances is this system supposed to work?	Under what restrictions is this system supposed to work?	What output is this system supposed to produce?	How can one determine the adequacy of the output?
Functional Purposes	What are the functions that make up what this system is supposed to be?	What are the purposes or applications of this system's job?	What environmental circumstances are relevant to this system's work?	What elements of the restrictions are relevant to this system's work?	How should the output relate to the system's functions?	How can one determine the adequacy of the functions' outputs?
Characteristics	What are the elements that make up the system's functions?	What capabilities are needed to achieve those purposes?	What are the limits or bounds of those elements that apply to this system?	What are the limits or bounds of those elements that apply to this system?	What are the elements of those output function relationships?	How can one determine the adequacy of those elements?

Figure 4. Preliminary Principles/Guidelines for Organizing System Taxonomies

total system performance. Finally, many systems act in concert with other systems in an interactive network of input and output. All of this is simply to say that the operation and performance of any system of interest has to be viewed in the context in which that system actually exists.

Recognition of this fact led to the inclusion of a third dimension in the STM, corresponding to the "system hierarchical structure." This expanded STM concept can be visualized as a family of matrices, one of which corresponds to the system being studied, and one to each interacting subsystem, collateral system, and suprasystem. Figure 5 displays a general representation of a system hierarchical structure, and Figure 6 shows the three-dimensional STM corresponding to that structure.

The third dimension of the STM system hierarchical structure is intended to insure that proper attention to interacting entities is given in any system measurement process. The hierarchical structure includes every system with which the system of interest directly interacts. The simple bicycle-rider system can elucidate this point. That system forms an integral (if minor) part of the total ground transportation system. It interacts directly with the traffic control system. It coexists with all other ground transportation mechanisms, e.g., cars, trucks, buses, motorcycles, other bicycles, joggers, etc., and shares numerous facilities with them. Any meaningful measurement of bicycle-rider system performance/effectiveness must take due account of the impact of all of these other systems as factors facilitating or impeding the bicycle-rider system.

In general, a system interacts directly with:

- larger systems, of which it is a part, and superior systems, to which it is subservient in a command/control sense; collectively, these larger and/or superior systems are termed suprasystems in the hierarchical structure

- smaller systems that comprise it, and inferior systems over which it exercises command/control. Collectively, these are termed subsystems .

- systems that exist and operate on their own level of command and control, with which they share resources and/or exchange input/output. Collectively, these are called collateral systems.

Theoretically, it is probably possible to extend the hierarchical structure almost indefinitely in the vertical direction. That is, subsystems might divide into sub-subsystems, which in turn break down into sub-sub-subsystems, etc. Similarly, suprasystems might point toward supra-suprasystems, and so on. However, at the present stage of development of the STM as a component of the total performance measurement process, it is felt to be sufficient to limit the view of a system's context to those entities with which it directly interacts, on its own hierarchical level (collateral systems), the immediately superior level (suprasystems), and the immediately lower level (subsystems).

The point of this discussion concerning the hierarchical structure surrounding some system of interest is this: the interacting, "neighboring" entities very likely exert influence on what the system of interest is supposed to do and on

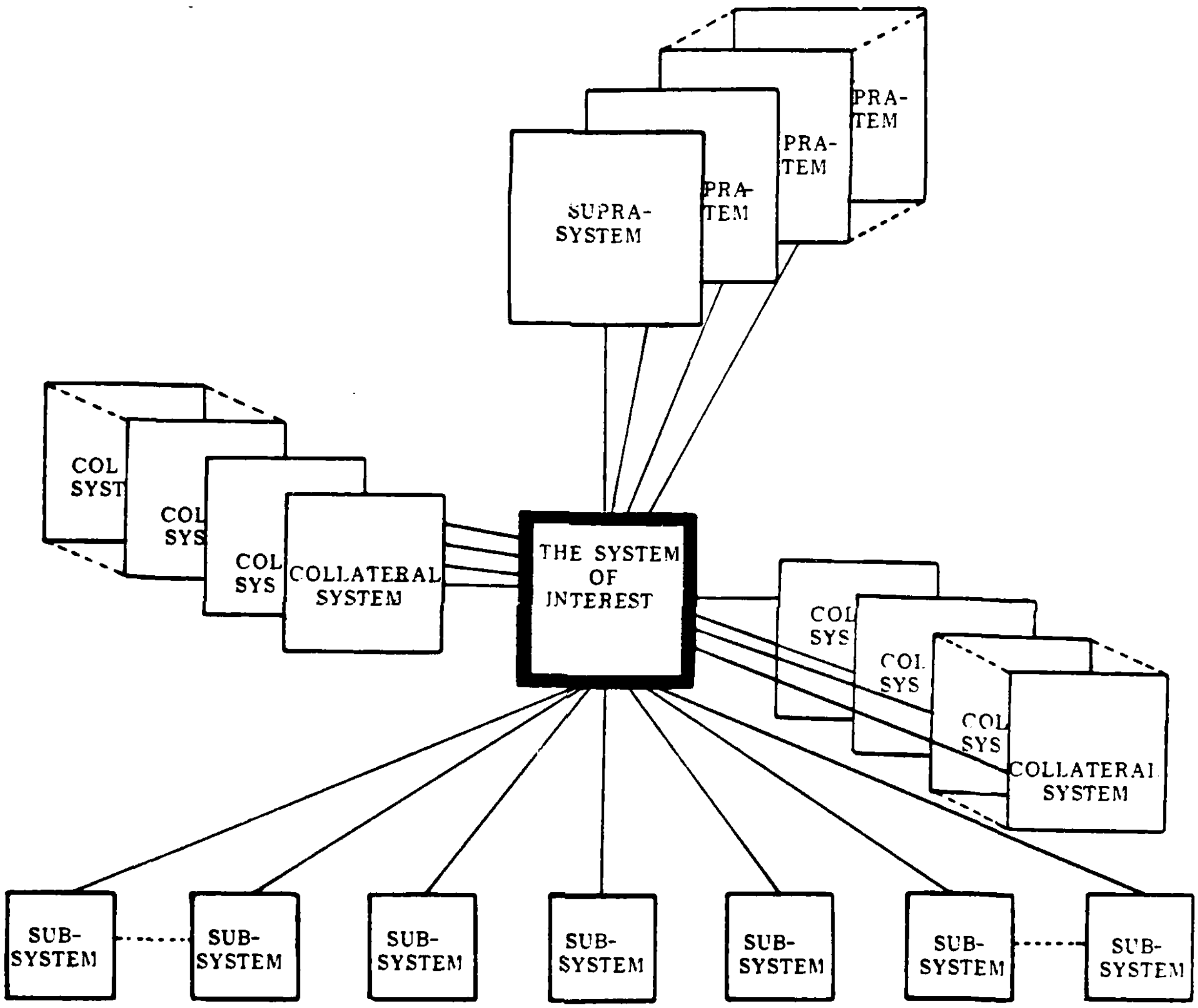


Figure 5. General Representation of a System Hierarchical Structure

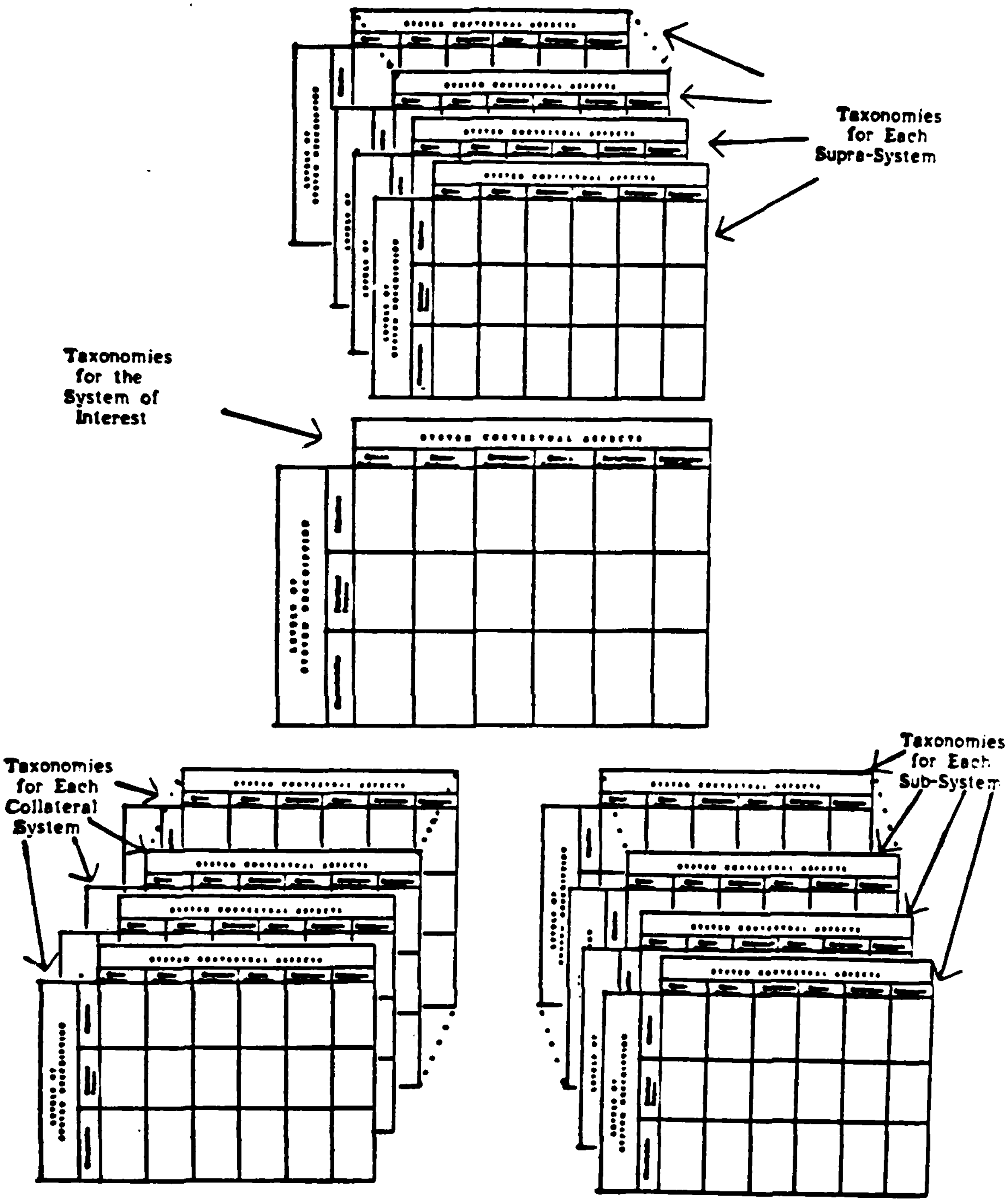


Figure 6. The Three-Dimensional Structure of the STM

how well, when, and where it can perform. The missions and performance requirements of a suprasystem, for example, certainly will impose jobs and requirements on the system of interest, because that system exists, in part, to serve the purposes of the suprasystem. Similarly, the performance capability of a subsystem might represent a basic limiting factor for the system's own performance. Finally, to the degree that the system needs input from a collateral system, the ability of the system to do its job will be limited by how well the collateral system does its job. To the degree that the system must supply input to a collateral system, the collateral system's performance requirement will have some determining influence over the system's own requirements.

Much like the second taxonomic dimension (contextual aspects of measurement), this third dimension is inextricably linked with a specific measurement application. That is to say, the situation or specific scenario within which a system's performance/effectiveness is to be measured will determine how many and what types of other systems will interact with that system of interest. Thus, system hierarchical structure is incorporated into the taxonomization process as a means of insuring that the performance/effectiveness measures ultimately selected are specifically relevant to the measurement problem and context at hand. Like the other two dimensions, the hierarchical structure has been included in the STM as a mechanism for identifying and organizing populations of systems, and reflects the basic STM philosophy that knowledge of the system populations associated with a system under study will contribute much to the measurement of that system's performance/effectiveness. Unlike the other two dimensions, however, the hierarchical structure helps the analyst focus on populations to which the interacting systems belong, rather than on the system's own populations. The system in question always should be the major source of variables for its own measurement, but it should not be the only source of variables. Important input also must be drawn from the system's interfaces with its neighbors.

Preliminary Application of the Three Dimensional STM

At this point in the research, the taxonomization process was applied to two systems that, although still relatively simple, were significantly more complex than were the very simple examples that had been used as the vehicles for deriving preliminary guidelines. Those two systems were the individual mobile citizens' band radio system and the squad automatic weapon (SAW) system. The application of the evolving STM to those systems was intended to permit further refinement/clarification of the taxonomization guidelines so that subsequently the model might be applied to still more complex systems.

Figure 7 displays the system hierarchical structure defined for a (simplified) study of the individual mobile CB system. In the course of that study, and in the parallel study of the SAW, arrays of taxonomies were prepared for several systems. Figures 8, 9, and 10, respectively, exhibit taxonomy sets for the individual mobile CB system itself, for the collateral emergency all-hours reporting system, and for the CB network suprasystem.

The identification of these and similar taxonomy sets provided considerable insight into the taxonomization process, and led to significant clarification of the preliminary guidelines. In addition to the questions posed to suggest the kinds of system populations relevant to each "cell" of the STM, it was possible to derive some instructions concerning how those questions could be answered. The

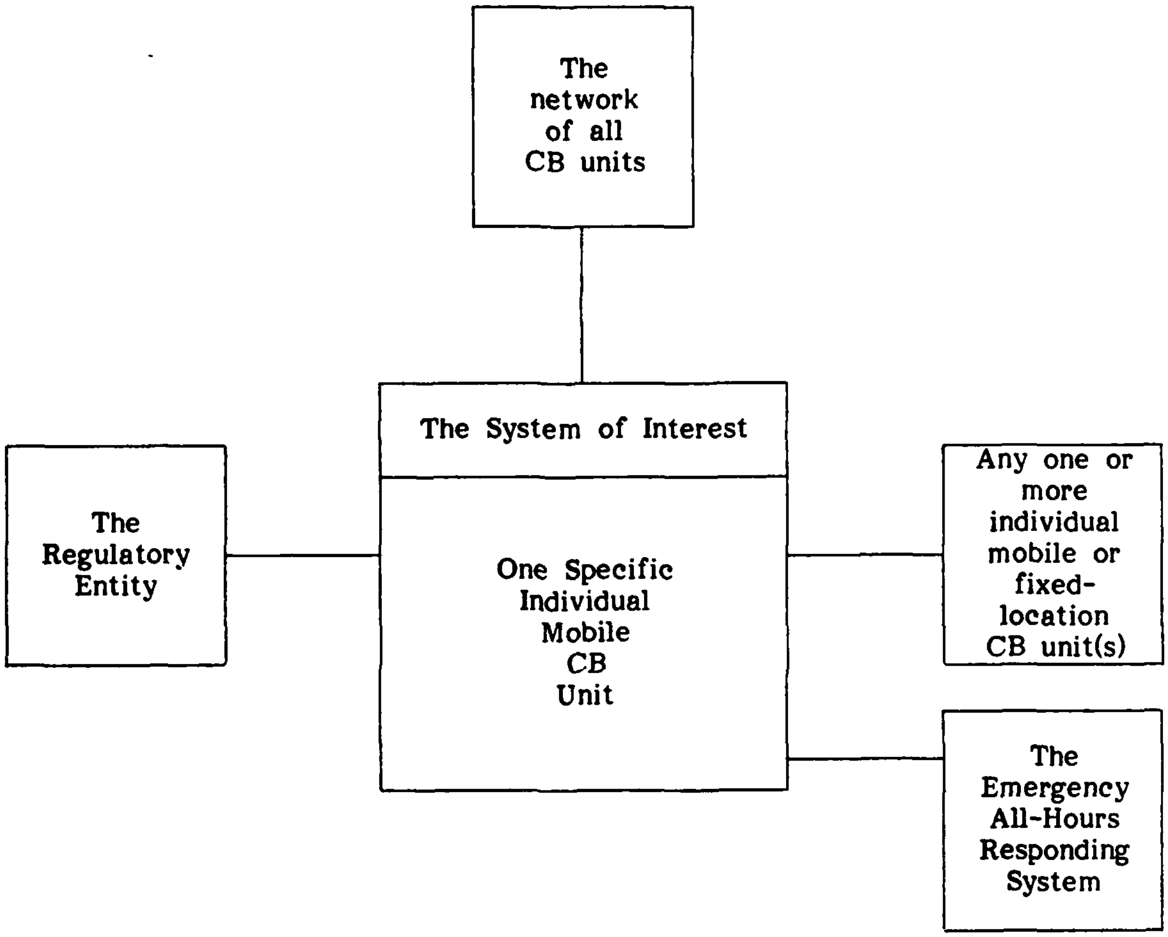


Figure 7. System-Centered View of the Individual Mobile CB System Hierarchy (Case Study)

	SYSTEM DEFINITION	MISSION DEFINITION	ENVIRONMENT SPECIFICATION	GENERAL CONSTRAINTS	PERFORMANCE REQUIREMENTS	PERFORMANCE CRITERIA
OBJECTIVES	Two-way voice communication Communication from motor vehicle	Given desire for specific information request such information from other units Given that information is transmitted to this system, receive that information Given possession of information of interest to other units, transmit such information to those units	The system must be fully operable within the total set of environments in which the motor vehicle is operable	Operable by motor vehicle drivers Costs compatible with private ownership of system by a large segment of the driving population System operation must not interfere with vehicle operation System must remain operable when vehicle is disabled	Transmit voice messages capable of being received and understood by intended recipients Receive and understand voice messages of relevance to this system	Transmitted messages must reach the intended recipients Messages intended for this system must be received Messages must be intelligible by the intended recipients
FUNCTIONAL PURPOSES	Voice message transmission Voice message reception Communication with fixed-location and mobile units Communication while stationary Communication while in motion	Summon assistance in emergencies Foster personal security Avoid travel hazards and other critical situations Facilitate travel Conduct social conversations Conduct business conversations	Locations to which motor vehicles routinely may have access All circumstances under which motor vehicle travel may be required	Operators require no special, knowledge, skills or attributes Low costs of purchase, installation and maintenance No degradation of vehicle safety Able to continue critical communication services during vehicle disabled situations	Transmit information requests relevant to emergency assistance, travel, traffic and roadway conditions, social exchanges and business exchanges Receive information requests relevant to the above Transmit information content relevant to the above Receive information content relevant to the above	Must be able to generate requests for information/assistance when needed Must be able to receive responses to such request when available Must be able to supply information when it is available
CHARACTERISTICS	Radio frequency signal transmission Radio frequency signal reception Transmission and reception while stationary or moving Communication "in clear"	Access to sources of emergency assistance Access to sources of travel-relevant information Ability to address specific other units Ability to recognize communications addressed to this system	All publicly accessible streets, roads, highways, etc. designed for motor vehicular use All speeds and directions of motor vehicular travel All traffic conditions All temporal conditions All climatological conditions	No formal training required to install or operate System "start-up" costs (purchase and installation) not to exceed $100 No distraction/impedence of driver's control of vehicular subassembly Ability to conduct emergency communications despite vehicle disability	When in need of specific assistance/information be able to contact units which can aid in obtaining the assistance/information When contact is made with other communicating unit(s), be able to exchange appropriate information Ultimately must satisfy the purposes for which the communication is conducted	Must obtain all requested information/assistance accurately, completely, and in a timely fashion

Figure 8. System Taxonomies for the Individual Mobile CB System (The System of Interest)

	SYSTEM DEFINITION	MISSION DEFINITION	ENVIRONMENT SPECIFICATION	GENERAL CONSTRAINTS	PERFORMANCE REQUIREMENTS	PERFORMANCE CRITERIA
OBJECTIVES	Emergency notification Assistance dispatching Disaster area communication	Given transmission of a request for emergency assistance, insure reception of that request Given reception of such request, insure that appropriate assistance is provided Given a disaster-affected area, support the area's communication needs	The system must be fully operational nationwide at all times.	Operable by volunteer operations of fixed-location CB units using their own standard equipment All system costs must be covered by private contributions (no governmental funding)	Detect and receive transmitted requests for emergency assistance Insure delivery of emergency assistance to requesting parties Provide basic communication services to support delivery of emergency service	All properly transmitted emergency requests must be received Proper assistance must be delivered in a timely fashion Communication into and out of disaster areas must be maintained
FUNCTIONAL PURPOSES	Emergency assistance request reception Specific assistance Requirements diagnosis Assistance delivery support Critical communication maintenance	Receive all CB radio transmissions requesting Emergency assistance Determine appropriate types and sources of assistance Notify appropriate sources of assistance Provide communication support during delivery of assistance Provide a basic communication system for disaster areas	System must be accessible to CB unit operators under all environmental conditions that may apply to those units System must provide continuous CB radio emergency message monitoring in all geographical areas in which people reside	Operators must be knowledgeable and skillful in efficiently eliciting pertinent *information from* assistance seekers Operators must be knowledgeable and skillful in identifying and accessing proper sources of emergency assistance Operators must be able to remain calm and effective during crises	Determine the specific kinds of assistance needed Notify the appropriate *sources of assistance* Aid sources of assistance in getting their assistance to those in need Obtain all necessary information from requesting parties to facilitate delivery of proper assistance	Types and amounts of assistance needed must be identified, accurately, *completely, and in a* timely fashion Sources of proper assistance must be contacted in a timely fashion and must be provided with all information needed to render aid All necessary communication support to responding to emergency services must be given
CHARACTERISTICS	Continuous monitoring for emergency requests Rendering aid to individuals Rendering aid to disaster affected areas Support of emergency services communication needs	Guaranteed reception to all appropriately transmitted requests for emergency assistance Direct access to sources of appropriate emergency assistance Ability to provide communications into, out of and within disaster areas	System available at all times to both mobile and fixed-location CB unit operators whose individual systems are functioning normally and which are operated at locations under environmental conditions prescribed for those systems.	Training and periodic evaluation is needed to insure that operators possess sufficient skills and knowledge in interpersonal communication, problem diagnosis, crisis intervention and crisis management	Continuously monitor for emergency assistance requests at all times and at all normal places of individual CB system operation Recognize and receive every properly transmitted emergency request Plan responses properly Maintain a communication link during emergencies and disasters	System must be available to receive proper requests from all individual CB unit operators All individual and area requests for emergency services must be satisfied Communication contact with and among emergency service agencies and personnel must be provided

Figure 9. System Taxonomies for the Emergency All-Hours Responding System (A Collateral System)

	SYSTEM DEFINITION	MISSION DEFINITION	ENVIRONMENT SPECIFICATION	GENERAL CONSTRAINTS	PERFORMANCE REQUIREMENTS	PERFORMANCE CRITERIA
OBJECTIVES	Large membership population voice communication Publicly accessible communication links via radio	Given individuals with communication desire and capability, provide mutual access to voice message exchange Given designated radio signal frequencies, provide a pool of private individuals and agencies with access to those frequencies	The system must be fully accessible and operational under the normal environmental circumstances that apply to any individual member	Equal opportunity to achieve membership must be available to every citizen of the nation who has achieved the age of full majority rights All members must have equal status within the population No public funds can be allocated to operation of the system Critical communications are to be given priority	Create and maintain a large pool of units with mutual voice message communication capability Maintain access to designated radio signal frequencies by members of the pool	Pool must be sufficiently large and sufficiently well distributed to permit any member to have communication access to the system Radio signal frequencies designated for the system msut be kept as easily and usefully accessible to members as possible
FUNCTIONAL PURPOSES	Multi-user voice message transmission Multi-user voice message reception Network sharing Mutual communication among many users	Mutual ability among members of large populations to exchange voice messages with each other Mutual ability among members of large populations to monitor the designated radio signal frequencies Mutual access, reasonably often, among members to transmission of signals on the designated frequencies	At all times, places and other circumstances where an individual member may initiate communication, the system must provide access to sufficient communication partners to insure that any critical message can be exchanged and to provide a reasonable likelihood of exchanging non-critical messages	No arbitrary or capricious restrictions on membership Network operating costs to be borne collectively by members Network procedures and practices must foster equal access/service to all members Network procedures and practices must provide for priority service to critical needs	Maintain members' abilities to monitor the designated radio signal frequencies Maintain and foster members' opportunities to transmit signals on the designated frequencies Facilitate exchanged of voice messages among members	Every member must be able to receive messages generated by enough other members to satisfy his/her information needs Every member must be able to transmit messages to sufficient other members to satisfy his/her needs
CHARACTERISTICS	Provision of many communication partners Provision of access to radio signal transmission Provision of access to radio signal reception Support of many private communication purposes	Ability of all members to receive messages from many other members Ability of all members, reasonably often, to send messages to many other members Reasonable opportunities available to all members to satisfy their needs for voice communications via radio	Available to members at fixed-locations and to members with mobile operations capability, in accordance with the environmental limits of either situation	Promote large membership Promote adherence by members to procedures and practices that maximize system benefit to all	Maximize the population of members with which each member can exchange voice messages Promote and facilitate satisfaction of all members' communication needs	

Figure 10. System Taxonomies for the Network of all CB Units (A Suprasystem)

updated taxonomization guidelines, seen in Figure 11 represented the major end product of the STM "first revision" effort. The guidelines were grouped into eighteen "cells," each corresponding to the intersection between one of the three levels of system description and one of the six contextual aspects of the system. Of course, in some measurement applications only one or two of the rows in this matrix may be pertinent. The analyst must determine the stage of development of the system of interest and the kinds of measurement issues to be faced in order to decide which of the three levels of system description are pertinent. Also, and most importantly, the analyst must apply taxonomization guidelines within the context of the measurement purposes he or she is addressing. If those purposes are restricted, the analyst might be concerned only with some elements of the system's definition, or only with certain of its missions, or only with a subset of its performance requirements, etc. It is not always necessary or appropriate to apply the STM to generate all of the system population categories to which the system belongs by virtue of its contextual aspects. It is only necessary and appropriate to identify those taxa that apply to the measurement purpose at hand.

The guidelines given for each "cell" of the "first revision" STM consisted of a question and a statement. The question was intended to focus the cell toward a specific set of taxa; the key operative word or phrase in each cell was underlined. Thus, for example, segments of the total matrix of taxonomies were directed toward identifying population categories derived from the particular system's functions, purposes, capabilities, functional outputs, etc. The statement following each question was intended to clarify the meaning of the operative word or phrase and to help the analyst apply the word or phrase to the system in question.

The Initially Revised STM: A Summary

The product of the first revision effort may be summarized as follows:

- The STM is a three-dimensional array of procedures and guidelines for identifying the various population categories of systems that might be relevant to some particular measurement of some particular system.

- The three dimensions that provide the structure of the STM correspond to (1) a set of general aspects of any human-machine system that represents the context of a system's performance; (2) several levels of system description, which reflect different kinds of measures and measurement issues and which adapt well to different stages of a system's development; and (3) the hierarchical structure in which the particular system of interest exists.

- The three-dimensional STM can most easily be viewed as a collection of two-dimensional planes (See Figure 6). Each plane corresponds to one of the systemic entities in the system hierarchical structure, i.e., a plane corresponds either to the system of interest itself or to one of the suprasystems, collateral systems, or subsystems with which it interacts.

	Taxonomies Derived From SYSTEM DEFINITION	Taxonomies Derived From MISSION DEFINITION	Taxonomies Derived From ENVIRONMENT SPECIFICATION	Taxonomies Derived From GENERAL CONSTRAINTS	Taxonomies Derived From PERFORMANCE REQUIREMENTS	Taxonomies Derived From PERFORMANCE CRITERIA
Objectives Level of System Description	What is this system supposed to be? Analyze the system's title, structure and basic general description and list all the distinct types of entities that this system is.	What job is this system supposed to do? Using the most basic description of the work for which the system is intended, list all distinct stimulus-response pairings that should be achieved. That is, each distinct job should be listed in the following format: "Given...(some input)...produce...(some activity)"	Under what circumstances is this system supposed to work? List all distinct types of time, place and ambient circumstances in which the system is supposed to be able to do its job.	Under what restrictions is this system supposed to work? List any a-priori limitation that is imposed on the system and/or its job.	What output is this system supposed to produce? List each distinct type of product, service or other end result that this system is supposed to provide.	How can one determine the adequacy of the output? Describe the conditions that each such product, service, or result is supposed to satisfy.
Functional Purposes Level of System Description	What are the functions that make up what this system is supposed to be? Break down each of the above-listed types of entities into the major system functions that they imply.	What are the purposes or applications of this system's job? List each type of reason why the above-listed jobs are to be performed.	What elements of the environmental circumstances are relevant to the system's work? List the factors or components of the times, places and circumstances that conceivably could affect the need for, or ability to do, the job.	What elements of the restrictions are relevant to the system's work? Break down these a-priori limitations into terms relevant to the system's functions and purposes.	How should the output relate to the system's functions? Decompose the above-listed products, services or results into their consistent intermediate products, services or results keyed to the system's functions.	How can one determine the adequacy of the functions' outputs? Describe the conditions that each intermediate product, service or result is supposed to satisfy.
Characteristics Level of System Description	What are the elements that make up the system's functions? Further break down each identified function into the elemental operations they imply.	What capabilities are needed to achieve those purposes? List the intermediate jobs, or tasks, that the system must be able to accomplish in order to satisfy the above-listed purposes.	What are the limits or bounds of those elements that apply to this system? Describe the range of each such factor.	What are the limits or bounds of those elements that apply to this system? Further break down these a-priori limitations into terms relevant to the system's elemental operations and intermediate tasks.	What are the elements of those output-function relationships? Further decompose the specified output into products, services or results keyed to the system's functional elements.	How can one determine the adequacy of these elements? Describe the conditions that each output element is supposed to satisfy.

Figure 11. "First Revision" of Taxonomic Guidelines

- The two-dimensional plane forms a 3-by-6 matrix representing the interaction between each level of system description (of which there are three) with each system contextual aspect (of which there are six).

- When one applies the STM, one develops sets of system population categories to which the system of interest or one of its subsystems, collateral systems, or suprasystems belongs. Each population category represents a source of variables of potential relevance to the measurement process.

- Having applied the STM, the analyst's task is to examine each system population category and to extract from it issues and implications for the performance measurement. This requires that the analyst have a clear understanding of the purposes behind the measurement application at hand, and of the nature of the interface between the system of interest and each of its subsystems, collateral systems, and suprasystems.

- Once all relevant measurement issues and implications have been extracted from the taxonomization process, the analyst may proceed to the focal stages and then to the planning and implementation stages of performance measurement in order to select the appropriate set of measures and apply those measures in the appropriate testing context.

C. Initial Application of the STM to the IFV

The taxonomic guidelines given in Figure 11 above were applied in an effort to identify relevant system populations for the Infantry Fighting Vehicle (IFV). A decision was made to focus on an IFV squad within a typical measurement application, namely, one in which the squad served as the platoon's bounding element in a bounding overwatch during an offensive maneuver within an armored threat environment. As a result of this application, considerable insight was gained concerning the viability of the STM as a tool for measuring system performance/effectiveness, and substantial progress was made toward improving the taxonomization procedures. Details of the trial application as a learning experience are summarized below.

Overview of Trial Application Procedures and Findings

The original intention was to conduct the trial application of the "first revision" STM to the IFV in a quasi-clinical fashion, not unlike the constraints of a blind experiment. Thus, the project staff members who had developed the initial set of taxonomic guidelines were to detach themselves from the application, which was to become the sole responsibility of a third staff member who was well familiar with the IFV, but not directly involved in the initial revision of the STM. It was hoped that this procedure would help to uncover any need for clarification or further elaboration of the written guidelines as well as provide a test of the basic taxonomy modelling concept.

Very shortly after the trial application began it became evident that the guidelines shown in Figure 11 needed substantial clarification/elaboration. The abstract, often vague terms used in the guidelines forced the application analyst to query the development analysts repeatedly in an attempt to ascertain exactly what was being sought. For example, precise definitions (in the STM context) were sought for such terms as "entity", "functions", "intermediate tasks", "elements", etc. These questions, and the fact that they often proved difficult to answer, led to the realization that there was a more fundamental deficiency in the "first revision" STM: namely, the concepts imbedded in the three levels of system description and in the six contextual aspects of measurement were not yet very clearly grasped. The taxonomic guidelines were vague because the staff's understanding of the distinctions among system definition, mission definition, performance requirements, performance criteria, environment specification, and general contraints was itself vague. The same could be said of the distinctions among the objectives, functional purposes, and characteristics levels of system description. The application analyst was experiencing difficulty in identifying relevant system populations to which the IFV belongs largely because the principles for organizing those populations had not been clearly defined or grasped when the guidelines were written.

Faced with this impass, the original approach to the trial application was abandon^d, and a team effort was adopted. The application analyst and one of the guideline developers began to work together, starting with an in-depth review of the previous "simple system" STM applications in an attempt to isolate the key distinctions among the cells of the model. The team then pooled their analytic resources (i.e., IFV familiarity coupled with STM development experience) in the hope that the application would proceed more efficiently. As the trial application progressed, additional insight into the taxonomization process was gained. First, it was recognized that the three contextual aspects labelled System Definition, Mission Definition, and Performance Requirements actually represented three different views of what constitutes a system's performance. Each of these different representations contributes one essential aspect of performance measurement. They can be described as follows:

- System Definition is concerned with the system's performance potential. The analyst needs to know at the outset of any measurement application exactly what capabilities have been incorporated into the system under study (or, what capabilities supposedly have been provided).

- Mission Requirements* is concerned with the system's performance process. It is in this context that the analyst examines how a system performs.

- Performance Requirements is concerned with the system's performance products, i.e., the end results (goods, services, accomplishments, etc.) of its work.

* Originally, the term "Mission Definition" was used. However, "Requirements" is believed to connote better the process-orientation of this contextual aspect of measurement.

The triad of potentialities, processes, and products was felt to be a logical decomposition of the total scope of performance. Moreover, it is a decomposition that intuitively lends itself well to measurement, and that seems to account well for all measurement concerns that might arise at any stage of a system's life cycle.

As a second major insight, it was recognized that the Environment Specifications and General Constraints aspects of the measurement context are concerned with the factors that may impede the system's performance (either its potentialities, or its processes, or its products). Those two aspects conceivably could be grouped together under one column in the STM (e.g., a "General Impediments" column). However, it seemed helpful to preserve a distinction between the "environment" and "general constraints," based upon the following perception:

- Environment Specification covers any performance impeding factors that arise naturally from the circumstances or conditions of the situation at hand. In general, these are impediments to performance that are not subject to arbitrary manipulation. For example, once a time and place for an IFV mission or test have been selected, such factors as terrain and weather conditions would be part of the environment specification.

- General Constraints covers any performance impeding factors that are imposed on the system as a direct result of a conscious decision. Tactical movement constraints (e.g., "Stay off roads, trails") and other operating limitations (e.g., "maintain radio silence") are examples of this type of impediment as it might apply to the IFV.

The third major insight concerned the relationships among the three levels of system description. Every entry on any level is, of course, a particular population of systems. However, there is not a complete independence between the populations found on two different levels of description: rather, the simple system applications clearly disclosed that there is a complete interdependence among the populations on the three levels. The populations that are found on the topmost ("Objectives") level of description are defined by the distinct classes of performance potentialities, processes, and products of the system of interest (in the context of the particular measurement application), or by the distinct classes of naturally or consciously occuring factors affecting its performance. Each of those Objectives Level populations gives rise to a set of more narrowly focused populations on the Functional Purposes Level. These are identified by examining, for example, a particular performance potentiality (or process, or product) and then isolating the distinct reasons why the system is supposed to have that potential (or carry out that process, or produce that product). That is, on the Functional Purposes Level, one identifies the purposes for belonging to the populations previously found on the Objectives Level. The purposes themselves form a set of related, more specifically defined populations.

An example taken from the IFV trial application may clarify the relationship between the Objectives Level populations and their Functional Purposes Level counterparts. Among a number of distinct performance potentialities, the IFV squad must possess the capability of performing surveillance. Because of that fact, it belongs (on the Objective Level of description) to the population of all systems that perform surveillance. When one examines how the IFV is intended to apply that particular performance potentiality, one finds that it is to provide the IFV squad with the capabilities of:

- Conducting sector surveillance
- Detecting targets
- Acquiring targets
- Identifying/classifying targets
- Tracking targets

Thus, on the Functional Purposes Level, the IFV belongs to (among many others) five overlapping but distinct populations of systems, each defined by a distinct application (or purpose) of the potential for surveillance.

Each Functional Purpose Level population, in turn, gives rise to a still more narrowly focused set of populations on the Characteristics Level. These are identified by examining each purpose or application for a particular potentiality, process, or product so that the discrete ways in which the system can satisfy that purpose or application can be exhaustively listed. This is tantamount to identifying the constituent sub-potentialities, or sub-processes, or sub-products that make up each of the system's performance potentialities, processes, or products. For example, as was seen above the IFV squad belongs to a population of systems that have the potential for conducting sector surveillance. That is a population that emerges when the system is viewed on the Functional Purposes Level of description. In the specific case of the IFV, unlike many other members of that population, the purpose of conducting sector surveillance can be achieved by:

- Conducting sector surveillance with direct vision (unaided optics)

- Conducting sector surveillance with aided vision (image magnification, image intensification)

- Conducting sector surveillance with infra-red sensor.

Similarly, on the Functional Purposes Level, the IFV also belongs to the population of systems that have the potential for tracking targets. Many systems belong to that population (i.e., many systems can track targets). In the case of the IFV, the discrete target tracking capabilities include:

- Tracking moving targets while (IFV is) stationary

- Tracking moving targets while moving

- Tracking stationary targets while moving.

The recognition of the general-to-specific relationship between successive levels of system description of course existed at the outset of this project, but it was not until a careful study had been made of the STM's applications (to the various simple systems and to the IFV) that a clear definition of the structure of this relationship was achieved. That structure is as follows:

1. The Objectives Level of system description comprises all of the discrete potentialities, processes, and products that, collectively, define the system's performance, as well as the discrete categories of factors (both naturally - and consciously occuring) that may impede or otherwise influence the performance. Each such discrete potentiality, process, product, and factor defines a system population to which the system of interest belongs. In any given measurement application, the analyst is concerned only with the Objectives Level populations that impact on that application (i.e., not every application exercises all of the system's potentialities, processes, and products).

2. The Functional Purpose level of system description comprises all of the discrete purposes or applications for the potentialities, processes, and products identified on the higher level, as well as the (more specific) factors that may impede or otherwise influence achievement of those purposes/applications. Each such discrete purpose and specific factor defines a system population to which the system of interest belongs. Each of these populations is directly traceable to some population previously identified on the Objectives Level. In any given measurement application, the analyst is concerned only with the Functional Purposes Level populations that impact on that application (i.e., not every measurement application exercises all of the reasons why a system possesses some potentiality, carries out some process, or produces some product).

3. The Characteristics Level of system description comprises all of the discrete steps or ways in which the system can achieve the purposes identified on the preceding level, as well as the (even more specific) factors that may impede or otherwise influence the system's ability to accomplish those steps. Each such discrete step and specific factor defines a system population to which the system of interest belongs. Each of these populations is directly traceable to some population previously identified on the Functional Purposes Level. In any given measurement application, the analyst is concerned only with the characteristics Level populations that impact on the application (i.e., not every measurement application exercises all of the discrete steps or ways in which a system may achieve its purposes).

The insights outlined above constituted major progress in the project staff's understanding of the concepts imbedded in the columns and rows of the STM. One additional issue was clarified during the IFV trial application, namely, the role and scope of the sixth column, labelled "Performance Criteria." Throughout the first revision effort, that column had been considered to be linked exclusively with the "Performance Requirements" column, i.e., for each performance requirement expected of the system, there would be a corresponding performance criterion (or group of criteria). Once the STM's development had evolved to the point where it was clear that the entries in the "Performance Requirements" column represented only one aspect of a system's performance (namely, its products), the question remained whether the criteria column should also be exclusively product-oriented, or whether it should encompass standards of potentiality and process as well. A more fundamental question was also raised: Is it appropriate to include performance criteria within the scope of the STM, or are they an area to be addressed at a later stage of the overall measurement process? The basic purpose of the STM, after all, is to generate sets of measures of effectiveness/performance for a system of interest. It is only after the MOE/MOP hierarchies have been developed that it becomes meaningful to investigate and specify criteria of effectiveness or performance, because every criterion must be tied directly to some measure. Thus, it is only after the basic purpose of the STM has been satisfied that it becomes appropriate to deal with performance criteria.

Prior to the IFV trial application, there were insufficient data to answer those questions. Thus, a decision was made to retain the "Performance Criteria" column in the STM for the IFV trial application, and to keep the focus of that portion of the model exclusively on the products of performance. Upon completion of the trial application, an assessment was made of the need for retaining criterion-based taxonomies in the model and/or of the desirability of expanding the scope of such taxonomies beyond their current product-orientation. Based on that assessment, it was concluded that criterion specification belongs at a later stage of the measurement process.

To summarize, actual trial application of the STM to the IFV squad thus commenced with a reasonably clear understanding of the concepts and relationships represented by the columns and rows of the taxonomic matrix, but with very few explicit, written guidelines for identifying how those concepts and relationships manifest themselves in the context of one particular system and one specific measurement application. The two project staff members continued to work as a team, continually examining the mission scenario to isolate the potentialities processes, and products required, the purposes/applications for these performance elements, the ways in which those purposes were achieved, and the various factors impeding or otherwise influencing the performance elements. As might be expected, this team effort was very highly iterative, with many "false starts." The team members maintained a constructively critical attitude toward each others' analytic suggestions and results, so that no taxonomies were incorporated into the trial application until both parties concurred as to their relevance. The hope was that, as the IFV squad's taxonomic structure emerged from this rather slow and difficult analytic process, so would a set of specific guidelines that would facilitate replication of the process in future applications. That hope, fortunately, was justified. Further, results indicated that the system taxonomies that emerge from this analytic model do provide the basis for identifying satisfactory measures of performance/effectiveness for particular measurement applications. Details of the trial application are summarized in the following paragraphs.

Specific Application to IFV

It was intended that the application to the IFV as a test case would further define the role of the STM and of the taxonomies which can be obtained. Also, the application was expected to result in an outline of the measures of effectiveness (MOE) hierarchy appropriate for one measurement purpose. Although the principal reason for applying the STM to the IFV in this project was simply to test and improve the model, it was also an objective that the trial application would produce measures of IFV effectiveness and performance that could actually be used during future tests of that system. With these desired objectives in mind, candidate measurement purposes were considered in collaboration with the COTR. They included: various size military units and associated operational status evaluations; segments of the IFV Operational Test II; tactics and doctrine issues; and, training effectiveness testing. To keep this task within practical limits at this stage of STM development, a sample application for IFV squad operations against stationary targets was selected. The measurement purpose selected to the revised STM to the IFV was:

- To evaluate the combat readiness of an IFV squad serving as the bounding element of a platoon in bounding overwatch during an offensive maneuver within an armored threat environment.

This measurement purpose was chosen for several reasons:

- First, the IFV weapons system is a complex system and an attempt to apply the STM to a unit size larger than a squad at this stage of STM development would require a much larger/longer in-depth analysis. Even a complete analysis of squad operations would require analyses beyond the scope of the present effort.

- Second, a mounted operation with the squad activity limited to conducting bound overwatch maneuvers and an engagement with a stationary armored threat was selected primarily to keep the number of variables manageable.

- Third, at the time of this work, no training circulars or field manuals existed, which described IFV squad or higher unit operations. It was intended that this application would serve as a useful experience in utilizing available system documentation and adapt information/doctrine from similar type systems as would a military analyst in applying the methodology to a new system.

The specific steps followed in applying the STM to the IFV under the above-noted conditions are described in the following paragraphs.

Assumptions Made with Regard to the System of Interest

In applying the STM to an IFV Squad, certain assumptions had to be made about the system of interest to simplify the taxonomization process and to enhance the generalizability of the results. The assumptions made were with regard to the qualifications of the IFV squad/platoon personnel and the IFV Table of Organization and Equipment (TOE). These assumptions were as follows:

- The IFV/Squad/Platoon personnel are MOS qualified and have completed the necessary unit team training in order to participate in combat readiness exercises.

- The IFV squad is manned by TOE authorized levels. For the purpose of this application, the assumption was made that the IFV squad consists of nine personnel, i.e., Track Commander, Gunner, Driver and six (6) Firing Port Operators, one of whom is a fire team leader.

- The IFV is prepared for this mission with maximum authorized TOE supplies and equipment.

- The IFV squad will remain mounted during the entire tactical operation and would only dismount personnel if absolutely necessary, e.g., prepare vehicle for fording, etc.

Determine the Hierarchical Structure in Which the System of Interest is Imbedded

Figure 12 depicts the external view of the hierarchical structure providing the immediate context of the IFV Squad. For this measurement purpose, the system of interest is imbedded in a subsystem/system/suprasystem structure that encompasses an IFV Platoon. Within the system of interest there are two subsystems: (1) the Carrier Team Subsystem, consisting of the Track Commander, Gunner and Driver with their associated work stations and equipment and (2) the Crew Compartment Team Subsystem, consisting of the six Firing Port Weapons Operators and their associated workstations and equipment. The two subsystems could be further divided into sub-subsystems which would bring the level to individual system operators and their associated equipment. However, considering the measurement purpose, this level is beyond the application interest of the STM. As depicted in Figure 12, the collateral systems include two (2) other IFV squads, one (1) IFV squad/platoon headquarters and the threat system(s). The suprasystem is the IFV platoon.

In applying the STM, one should develop the total number of taxonomic sets to which the system of interest belongs, including sets for each subsystem and corresponding sets for the collateral systems and for the suprasystems. The development of taxonomies for the various system levels leads to the identification of system-level interactions which influence relevant performance requirements and in turn affect performance measurement issues for the system of interest.

Define and Review Scenarios and/or Documents Required for This Application

In order to become thoroughly familiar with the IFV Squad/Platoon system, available system documents were reviewed. Those documents included the IFV Materiel Needs document, IFV Systems Specifications, Mission Scenarios, IFV System Task Descriptions, and Field Manuals (for similar systems) that provided guidance with regard to tactical operations. As a point of departure and initial guidance with regard to the measurement purpose, use was made of the Mission Scenario #1 (Bounding Overwatch Operation) from the IFV/CFV Personnel Selection Study.* That scenario is reproduced here in Figure 13. A squad verbal order was also developed to serve as guidance, and to aid in the identification of system population categories relevant to the contextual stages of the measurement process. The verbal order is presented in Figure 14, along with its associated map in Figure 15.

*Bloom, R.F., Pepler, R.D., Schimenz, M.V., and Lenzycki, H.P., IFV/CFV Personnel Selection Analysis. Darien, CT: Dunlap and Associates, Inc., July 1979. (Army Research Institute Research Note 80-41)

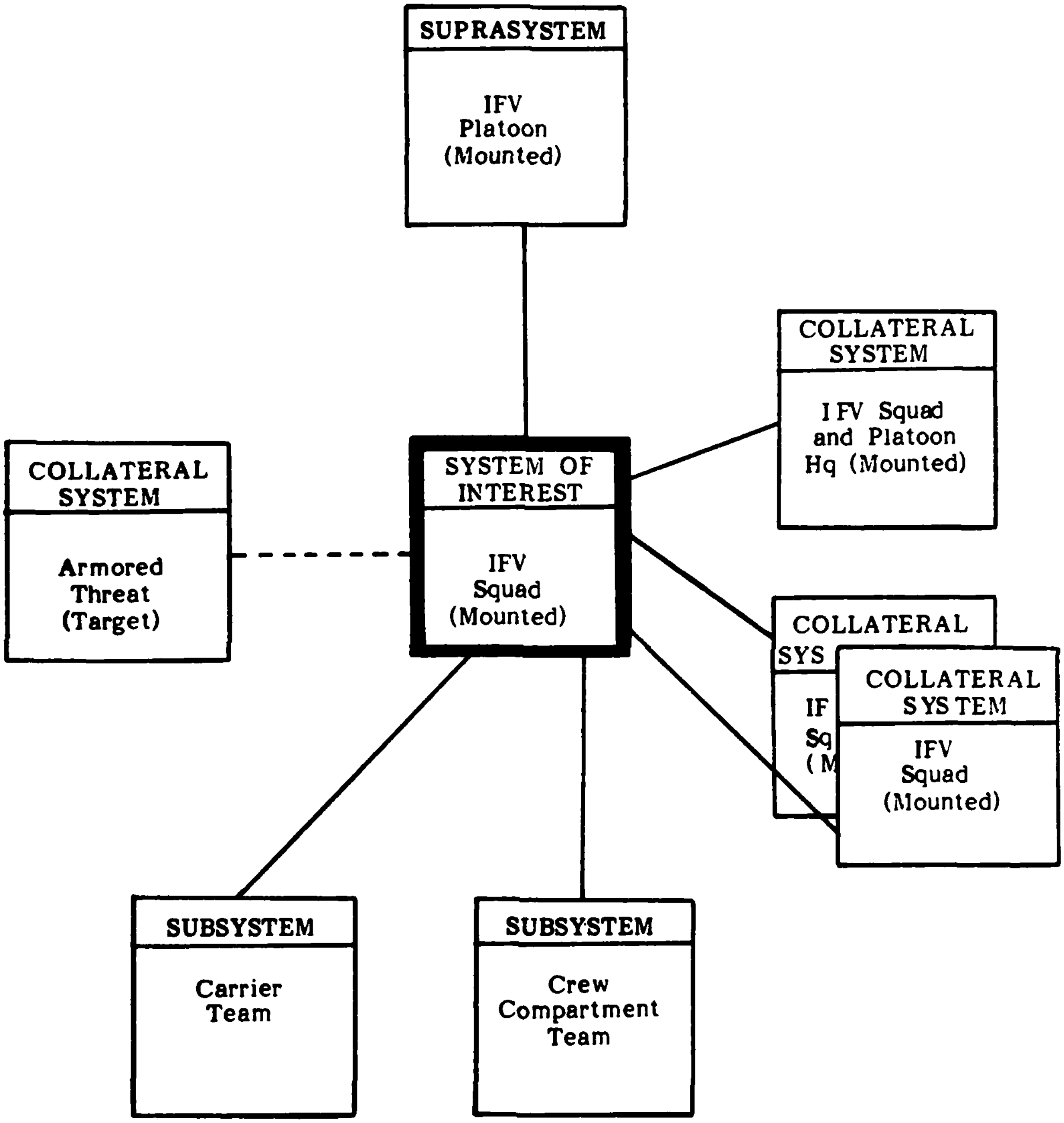


Figure 12. Hierarchical Structure Encompassing the IFV Squad System

TIME Min:Sec.	EXTERNAL SOURCE	TRACK COMMANDER	GUNNER	DRIVER	SQUAD AREA CREW (No. 4-9 FPWO's)
		INITIAL CONDITIONS - Platoon located at hill 450. Approaching hill 452. Mission - secure hill 452. - We are bounding element of 4 vehicle (IFV) platoon. - Daylight, contact expected. - Hill 452 is 1500M NE of 450. - Radio silence until contact. - Popped hatch mode on all vehicles. - Platoon (-) in overwatch on hill 450. - Initial bound to be 300m. - Vehicle prepared for move, turret weapons "battle sight." - TC has assigned sectors of surveillance to crew and general route to Driver.			
0:00	Platoon Leader Hand Signal	Receive hand signal to initiate bound			
0:03		Order "Driver left, move out" Observe turret indicator lights Select stabilization "On" Observe stabilization "On" indication	Announce "placing turret in motion" (IC) Observe turret indicator lights	Maneuver vehicle - - Depress foot brake - Release hand brake - Set driving range selector to "Drive" - Observe route of desired heading	Announce "turret deck clear" (FTL via IC) Observe assigned areas through vision blocks; FPWs at ready position (crew)
0:08		Observe assigned sector Maintain air surveillance	Squeeze palm switch and turn control handles to left Observe assigned surveillance area. Note turret reaching left sector limit.	Announce "Moving Out" Release foot brake, depress throttle Maneuver vehicle to desired heading	↓ (Continuous)

Figure 13. Mission Scenario
Mission Segment: Offensive Operation: Squad is Bounding Element
Bounding Overwatch - Contact Expected

TIME Min:Sec.	EXTERNAL SOURCE	TRACK COMMANDER	GUNNER	DRIVER	SQUAD AREA CREW (No. 4-9 FPWO's)
		Observe direction of movement and terrain Select and announce route changes to Driver ↓ (continuous)	Turn control handle right ↓ (continuous)	Maneuver vehicle in accordance with TC directions (continuous) (Vehicle moves about 200m)	
2:00	Muzzle Flash	Detect muzzle flash to right front in vicinity of hill 452			
2:01		Recognize target (mental process)			
2:02		Order hatches closed while closing own hatch.			
2:03		Grasp TC control handle, slew turret to vicinity of target. (May give verbal warning)	Observes/detects turret in TC override Closes hatch	Closes hatch, continues to observe type of terrain and continues to maneuver vehicle over selected route avoiding obstacles (trees, ditches, boulders, etc.)	
2:05		Observe target in alignment with vane sight	Observes target in unity window in day/night sight		
2:08		Order "Gunner, Battlesight, PC, direct front 1000 meters (estimates range)	Hears initial fire commands via IC and initiates response	Hears initial fire commands via IC	Hears initial fire commands via IC

Figure 13. (Continued) Mission Scenario
Mission Segment: Offensive Operation: Squad is Bounding Element
Bounding Overwatch - Contact Expected

TIME Min:Sec.	EXTERNAL SOURCE	TRACK COMMANDER	GUNNER	DRIVER	SQUAD AREA CREW (No. 4-9 FPWO's)
2:10	Enemy Shell Impact	Observe shell impact direct front Announces, shell impact via IC	Shifts head and eye to day/night sight and observes target using 4X. Observes shell impact direct front. Hears TC's communication	Observe shell impact direct front. Hear TC's communication	Hears shell impact and TC's communication
2:11		Radios target information to overwatch element (as required) and observes target in TC day/night sight optical link	Moves gunner control handle to align target with optical reticle (continuous) and selects 12X on sight	Decides on required vehicle orientation with respect to target	
2:13		Verifies foe and orders "fire"	Identifies target as foe. Announces "foe."	Selects route offering best fighting position (mental process) and maneuvers vehicle accordingly	Maintain surveillance of assigned areas and monitor fire commands (continuous)
2:14		Continue to observe target in TC day/night sight optical link	Place master ARM/SAFE switch to ARM (right hand)	Maintains a steady platform during conduct of fire. Informs Gunner of any directional changes (as required)	
2:15	Enemy muzzle flash	Detect muzzle flash	Detect muzzle flash	Detect muzzle flash	
2:16	Platoon order to seek cover and concealment	Receives platoon order	Squeezes trigger Fires bursts Hears platoon order	Hears platoon order	Hears platoon order

Figure 13. (Continued) Mission Scenario
Mission Segment: Offensive Operation: Squad is Bounding Element
Bounding Overwatch - Contact Expected

TIME Min:Sec.	EXTERNAL	TRACK COMMANDER	GUNNER	DRIVER	SQUAD AREA CREW (No. 4-9 FPWO's)
2:17		Order "Driver, left"	Tracks target	Maneuvers vehicle left	
2:21		Observes bursts with respect to target	Observes/senses bursts (visual/mental process)		
2:22		Advise Gunner of azimuth, elevation corrections (optional)	Applies corrections via gunner control handle and sight picture		
2:24		Order "Driver, straight"		Maneuvers vehicle straight ahead	
2:25	Enemy shell impact	Observe shell impact right rear	Squeeze trigger, fires bursts		Observe and report shell impact right rear
2:30		Observe own and overwatch element bursts on target	Observe own and overwatch bursts on target		
2:35	Platoon communication "target suppressed"	Receives communication	Hears communication	Hears communication	Hears communication

Figure 13. (Concluded) Mission Scenario
Mission Segment: Offensive Operation: Squad is Bounding Element
Bounding Overwatch - Contact Expected

SITUATION

"We are going to conduct an attack at 0600 hours today. This terrain sketch I've made represents the ground we've got to cover. As you can see the attack will cover a distance of about 3 kilometers. These little hills, 549 and 546 are platoon intermediate objectives. Hill 553, west of Lahm is the platoon objective. We are presently on Hill 578. From what I was able to see from the limited recon with the platoon leader, it looks like the enemy has withdrawn to positions north of Lahm. Although I didn't see any armored vehicles, Lt.Davies said the enemy has been identified as part of a motorized rifle unit. That means we have to be on the lookout for BMPs and maybe some tanks. We may also encounter such obstacles as minefields and wide trenches. The minefields are more than likely going to be forward of the trenchlines."

"Throughout the attack we will stay mounted. The 1st Platoon will be on our left and the 3rd Platoon on our right. The platoon objective is going to be hit with artillery and mortar fire just before we go in. The company has tanks attached to support us through the attack.

MISSION

"Our mission is to attack each of these intermediate objectives and final objective. We have to clear the trenches and bunkers in our zone. Upon securing Hill 553 we are to prepare defensive positions. Once we're there and see the terrain we'll talk more about it. We will move out at 0600."

EXECUTION

"When we move out, the platoon is going to be using bounding overwatch and we are the bounding squad. With the platoon overwatching us from this hill, we will move up this draw until we get to the patch of woods. I couldn't see much of these woods; so once we get close I'll guide the track over the remainder of the route. As soon as the rest of the platoon moves up to us, we'll bound around to the left and up this ridge line. I could see it pretty clearly, and I don't think anything is up there. When the rest of the platoon has moved up and all the tracks are in position we'll wait for Lt. Davies' order to bound to the first intermediate objective, Hill 549. Once we've taken Hill 549 we'll wait for Lt. Davies' order to continue bounding overwatch. It's important that we don't get too far ahead or behind the rest of the company. If we detect a mine field we'll try to go around it so keep your eyes open."

"If we have to dismount, the platoon sergeant will be controlling the fires of the carrier team but that is very unlikely. Our priority is to engage any armored vehicles in our sector and then bunkers."

(Continued)

Figure 14. Verbal Squad Order
Purpose: To Attack Hills 549,546 and 553 (Lichtenfels, Deutchland)

"When we get to the trenches and enemy contact is made, Sgt. Jones will control the fires of the FPWO's. Don't take any chances; lay down a good base of fire. Report all possible targets for the carrier team."

SERVICE SUPPORT

"Sgt. Jones, you make sure that the squad compartment and crew have the required basic load and equipment. Let me know when you're all complete. I'll check the carrier team supplies and equipment."

"McCarthy, the POL track will be here around 0430; make sure our fuel tank is topped off."

"Take care of any casualties within the track; give him some quick first aid and get back to your position. The company aid track will come forward just as soon as each intermediate and final objective is secured."

COMMAND AND SIGNAL

"We will cross the SP at 0600 on Lt Davies' hand signal. We will maintain radio silence until we reach Hill 549. During the attack no unnecessary Intercom chatter."

"In case I get hit, Sgt. Kowalski, you take over; our call sign is TANGO 31."

"OK, the time is now 0230; I will inspect at 0515 hours. It will be daylight at 0545. We have less than 4 hours before we move out. We will maintain radio silence until contact with the enemy is made. The platoon and the squad will use arm and hand signals during the maneuvers. Remember to maintain light and noise discipline. Do you have any questions? If not, get ready."

END

Figure 14. (Concluded) Verbal Squad Order

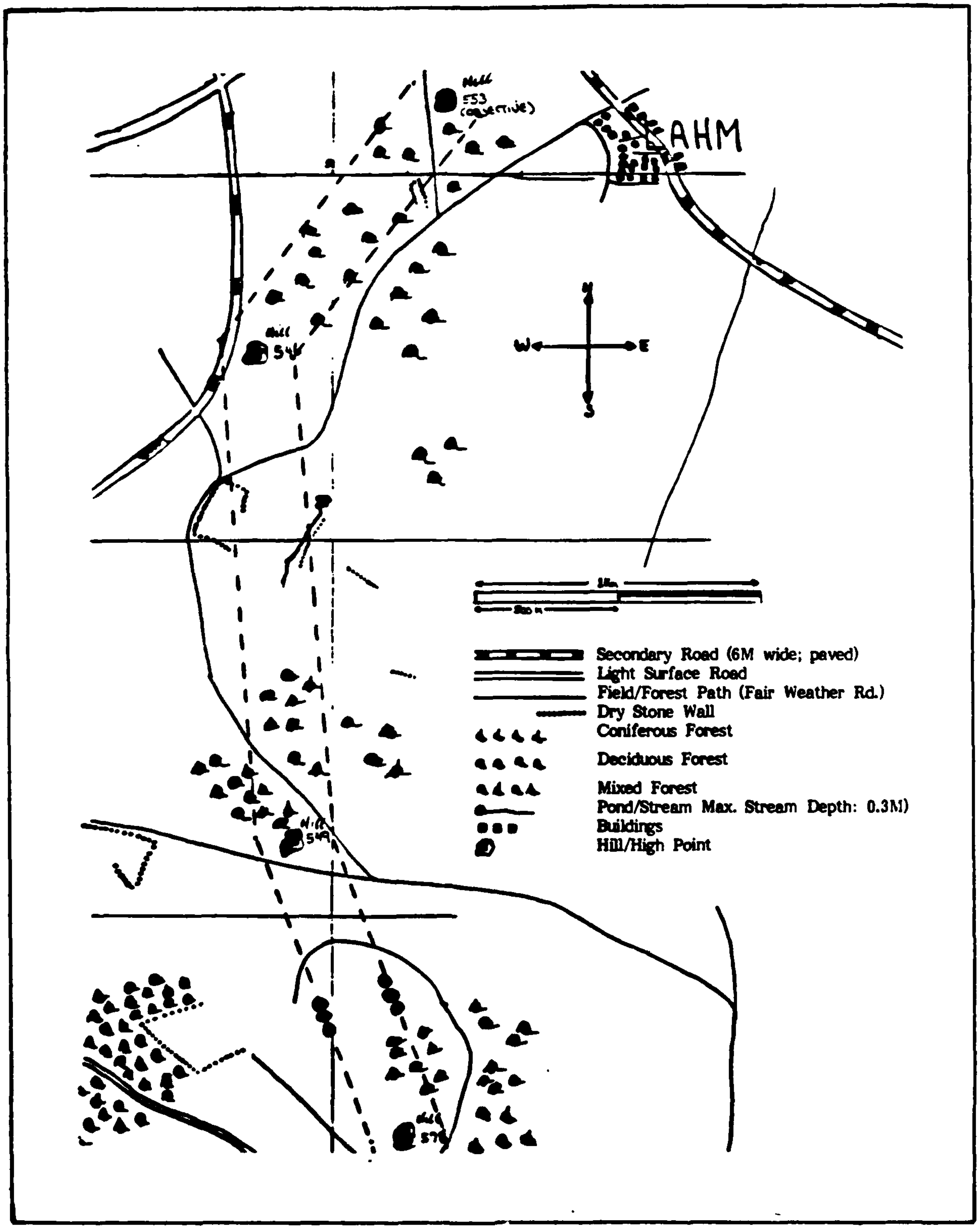


Figure 15. Map of Platoon Attack

Specifying the measurement purpose also requires description of the measurement conditions. These include such factors as the geographic area(s) in which the system is to perform its mission, the time period during which the system is to perform its mission, the weather conditions and any other limiting variables. As noted in the verbal squad order for this application, the geographic area selected is a temperate zone of operations in Southern Germany, the time period of performance is 0600 to 1200 hours, the weather is defined as fair, no precipitation, and good visibility.

Begin Applying the STM to the System of Interest to Derive Taxonomy Sets

As shown in the hierarchical system structure in Figure 12, the system of interest has two subsystems, i.e., the Carrier Team and the Crew Compartment Team. The analyses were initiated at the subsystem level. The analyses of the subsystems were initiated first, since it was felt that combining the subsystem taxonomies would simplify the derivation of the taxonomy for the system of interest itself. The initial subsystem selected for analysis was the Carrier Team. The two analysts worked together as a team to derive the taxonomies for each of the contextual stages of the measurement process, in the course of which they also updated and refined the STM guidelines shown in Figure 11.

The STM first revision was applied to Carrier Team and Crew Compartment Team subsystems, separately, to derive the eighteen different taxonomy subsets. These correspond to the "intersections" of each of the three levels of system description (Objectives, Functional Purposes, Characteristics) with each of the six contextual stages of the measurement process (System Definition, Mission Definition, Environment Specification, General Constraints, Ultimate Performance Requirements, Ultimate Performance Criteria).

Establish a Systematic Coding Technique

The IFV system was found to be very complex, in contrast to the relatively simple systems used in developing the first revision to the STM. As the analysis progressed, it soon became apparent that procedures must be formulated to identify more systematically the population categories associated with the three levels of system description (Objectives, Functional Purposes and Characteristics Levels). The procedure adopted was to identify all the Objectives Level descriptions for a particular contextual aspect, e.g., System Definition. Once these were identified, then each Objectives Level description was analyzed to determine a Functional Purposes population category and its associated Characteristics population categories before analyzing the next functional purpose and its associated characteristics.

A decimal numbering coding technique was established to facilitate the categorization of all three levels of system description. Each contextual aspect was assigned a unique number, as follows:

1.0 System Description

2.0 Mission Definition

3.0 Environment Specification

4.0 General Constraints

5.0 Performance Requirements

6.0 Performance Criteria

At the Objectives Level, the population categories were assigned successive numbers in the first decimal position. For example, at the Objectives Level under System Definition, each population category was identified as 1.1, 1.2, 1.3, etc. To be specific, the taxa identified on the Objectives Level system description for the System Definition of the IFV Carrier Team were designated as follows:

1.1 Providing surveillance

1.2 Conducting weapons fire

1.3 Providing squad command and control

1.4 Providing transportation

1.5 Providing communication

1.6 Providing squad protection

The Functional Purposes Level descriptions were assigned a two-decimal code, i.e., 1.1.1, 1.1.2, 1.1.3, etc. To continue the above example, the Functional Purposes Level taxa of "1.1 Providing surveillance" were designated as:

1.1.1 Conduct sector surveillance

1.1.2 Ability to detect targets

1.1.3 Ability to acquire targets

1.1.4 Ability to identify/classify targets

1.1.5 Capability to track targets

The Characteristics Level of system description was assigned a three-decimal code, i.e., 1.1.1.1, 1.1.1.2, 1.1.1.3, etc. In subdividing the functional purpose "1.1.1 Conduct sector surveillance," the characteristics which describe what capabilities the system must have in order to satisfy that application were numbered as follows:

1.1.1.1 Visually conduct sector surveillance, ground and air, with unaided vision

1.1.1.2 Visually conduct sector surveillance with aided vision (image intensification, image magnification)

1.1.1.3 Visually conduct sector surveillance with IR sensory device during periods of low visibility

The decimal numbering of the population categories simply aids in organizing the population categories in such a way that our analyst can easily trace the sub-population categories of Objectives Level, Functional Purposes Level and Characteristics Level populations. Figure 16 presents an example of a numeric coding scheme which facilitated the categorization of the three levels of system description and the six levels of the system's contextual aspects.

	1.0 SYSTEM DEFINITION	2.0 MISSION REQUIREMENTS	3.0 ENVIRONMENT	4.0 CONSTRAINTS	5.0 PERFORMANCE REQUIREMENTS	6.0 PERFORMANCE CRITERIA
OBJECTIVES	1.1 Surveillance 1.2 Weapons operation 1.3 Command & control (squad) 1.4 Transportation (squad) 1.5 Communications (squad & platoon) 1.6 Protection (squad)	2.1 Serve as overwatch bounding element 2.2 Conduct air/ground sector surveillance 2.3 Conduct threat engagement 2.4 Conduct communications	3.1 Rolling terrain 3.2 Rural and agricultural land areas 3.3 Obstacles 3.4 Summer, fair weather, southern Germany	4.1 Surveillance limits 4.2 Communication restrictions 4.3 Movement restrictions 4.4. Equipment/personnel 4.5 Threat capabilities 4.6 Weapons restrictions	5.1 Squad bounds 5.2 Target detections	6.1 Position, distance, time time of bound 6.2 Actual detections, false detections 6.3 Successful engagement, minimum time, minimum resource expenditure
FUNCTIONAL PURPOSES	1.1.1 Conduct sector surveillance 1.1.2 Detect targets 1.1.3 Acquire targets 1.1.4 Identify/Classify targets 1.1.5 Track targets	2.1.1 Secure a forward position 2.1.2 Enable platoon movement	3.1.1 Hills 3.1.2 Valleys 3.1.3 Flat terrain	4.1.1 Continuous ground, air surveillance throughout sector 4.1.2 Observation of likely threat	5.1.1 Platoon security 5.1.2 Movement toward objective	6.1.1 Position to provide optimum forward security for overwatch element 6.1.2 Efficient advance toward objective
	1.2.1 Select weapons 1.2.2 Select ammo/fire rate 1.2.3 Determine target range 1.2.4 Load weapons 1.2.5 Aim weapons 1.2.6 Fire weapons	2.2.1 Locate threat signatures 2.2.2 Locate likely threat avenues of approach/positions 2.2.3 Locate actual threats	3.2.1 Fields 3.2.2 Roads 3.2.3 Farms 3.2.4 Forests	4.2.1 Secure communications 4.2.2 Communication for platoon command & control 4.3.1 Remain within sector 4.3.2 Maintain platoon visual contact 4.3.3 Minimize system signature 4.3.4 Maintain movement speed 4.3.5 Maximize platoon weapon support	5.2.1 Location of enemy 5.2.2 Intelligence 5.2.3 Tactical decision making	6.2.1 Locate all threats in minimum time 6.2.2 Accurate, complete intelligence gathering 6.2.3 Tactical decisions appropriate & timely
	1.6.1 Protect by armor 1.6.2 Control internal environ. 1.6.3 Provide life support	2.4.1 Coordinate platoon/squad movement 2.4.2 Exchange intelligence 2.4.3 Exchange information (intra-squad) 2.4.4 Coordinate weapons operations	3.4.1 Warm-hot climate 3.4.2 Daylight 3.4.3 No precipitation 3.4.4 Good visibility	4.6.1 Weapon fire within sector 4.6.2 Safe fire rates	5.3.1 Threat destruction/neutralization 5.3.2 Self protection 5.3.3. Seizure of tactical advantage 5.3.4 Denial of tactical advantage	6.3.1 Timely & efficient threat destruction/neutralization 6.3.2 Successful self protection 6.3.3 Efficient use of capabilities and terrain 6.3.4 (Same as 6.3.3)
CHARACTERISTICS	1.1.1.1 Visually survey sector (unaided vision), air, ground 1.1.1.2 Visually survey sector (aided vision), ground 1.1.1.3 Survey sector by IR, ground (low visibility)	2.1.1.1 Select bound position 2.1.1.2 Select bound route 2.1.1.3 Perform bound 2.1.1.4 Occupy position	3.1.1.1 Max. upslope of 8° 3.1.1.2 Max. length of upgrade of 251m	4.1.1.1 Unaided vision scan capability throughout sector 4.1.1.2 Aided vision scan capability throughout sector 4.1.1.3 IR vision scan capability throughout ground sector 4.1.1.4 Vision block scan capability throughout sector	5.1.1.1 Occupation of position 5.1.1.2 Communication of secured position 5.1.1.3 Support of overwatch via covering fire	6.1.1.1 Position affords max. fields of fire 6.1.1.2 Ability to communicate forward movement in secure fashion 6.1.1.3 Appropriate, timely, effective covering fire
	1.1.5.1 Track moving target while moving 1.1.5.2 Track stationary target while moving 1.1.5.3 Track moving target while stationary	2.2.3.1 Detect actual threats 2.2.3.2 Identify actual threats 2.2.3.3 Classify actual threats	3.2.2.1 Secondary roads 3.2.2.2 Light duty roads 3.2.2.3 Trails	4.3.2.1 Stay within visual communication limits 4.3.2.2 Maximize visibility to platoon	5.2.2.1 What was observed 5.2.2.2 How many observed 5.2.2.3 Where/when observed 5.2.2.4 Enemy actions	6.2.2.1 Accurately, timely, useful data 6.2.2.2 6.2.2.3 (Same as 6.2.2.1) 6.2.2.4
	1.2.5.1 Fine aim turret weapons 1.2.5.2 Gross aim turret weapons 1.2.5.3 Aim at ground targets 1.2.5.4 Aim at aerial targets	2.4.1.1 Receive platoon's movement instructions 2.4.1.2 Transmit movement instructions to platoon	3.4.1.1 Temperature range of 27° - 32° C 3.4.1.2 Relative humidity of 40-85%	4.6.2.1 Avoid weapon destruction/malfunction due to fire rate 4.6.2.2 Insure effective target engagement	5.3.4.1 Maintain system offensive capability 5.3.4.2 Maintain system defensive capability 5.3.4.3 Maintain control of terrain 5.3.4.3 Maintain tactical superiority	6.3.1.1 Max. self preservation while still effectively firing to destroy/neutralize 6.3.1.2 Accurate, timely conduct of fire 6.3.1.3 Damage threat 6.3.1.4 Accurate, timely assessment 6.3.1.5 Appropriate cease fire

Figure 16. Example of a Systematic Coding Scheme Applied to the IFV Carrier Team Unit

Identify Taxonomies and Clarify Procedures

As previously noted, a review of earlier taxonomization exercises (based on simple systems) preceded the identification of IFV taxonomies. That review yielded clarification of the procedures for identifying taxonomies. Additional clarification emerged during the course of the IFV trial application itself. Among the major areas of clarification were these three:

- The Respective Perspectives of System Performance

  The first three columns of the STM are directly concerned with whatever it is that constitutes "performance" of the system under study. The "System Definition" column is concerned with performance potential, i.e., the basic capabilities that the system possesses. "Mission Requirements" focuses on performance processes, i.e., how the system works. "Performance Requirements" addresses itself to the products of performance, i.e., the goods or services output by the system.

- The Contexts within Which the System Performs

  Two columns in the STM are concerned with identifying the factors that may impede or otherwise influence system performance. These are "Environment Specification" and "General Constraints." "Environment Specification" covers any such factors that arise naturally from the circumstances or conditions of the system performance situation. "General Constraints" covers those impeding/influencing factors that are imposed on the system as a direct result of conscious decisions. It is incumbent upon a measurement analyst to insure that such factors are identified and adequately reflected in the measurement situation and process.

- The Nature of the Levels of System Description

  The Objectives Level is concerned with the various aspects of system performance (potentialities, processes, and products) as discrete, indivisible entities. On that level, the focus is on what the system can do, not on why or how it does it.

  The Functional Purposes Level goes beyond the "what" of performance and concerns itself with the application to which the system's performance is to be put. The focus is on why the system is to have the particular potentialities, carry out the particular processes, and deliver the particular products.

  The Characteristics Level examines each application or purpose of performance in detail, and concerns itself with how the system can achieve that purpose. The emphasis is on the discrete ways in which each purpose can be accomplished, or the discrete steps or milestones that must be reached in order to satisfy the purpose.

Once the preceding major points were clarified, it became possible to continue the identification of relevant taxonomies for the IFV squad. The process of taxonomization initially was slow and laborious because the guidelines were relatively rudimentary. However, as progress was made, the guidelines steadily were refined and improved. Ultimately, complete taxonomies were developed for the IFV squad's two principal subsystems, viz., the Carrier Team Unit and the Crew Compartment Unit. For the former, 382 distinct (but closely related) system populations were identified as being relevant to the measurement application at hand. For the latter, 220 were identified. These are much larger than the taxonomy sets derived in the previous simple system exercises. (For the bicycle-rider system, by way of comparison, 64 relevant taxa were identified.) However, they appear to be manageable taxonomies, precisely because the STM establishes a workable organization for those taxonomies. Figure 16 displays a portion of the total taxonomy for the IFV's Carrier Team Unit. A complete presentation of that set is given in Appendix A; the taxonomy for the Crew Compartment Team is given in Appendix B.

D. Derivation of an IFV Measures Hierarchy for the Surveillance Function

As a test of the utility of the IFV taxonomy, a set of measures was derived from those taxa associated with the Carrier Team Unit's performance of surveillance. The basic purpose behind the identification of system taxonomies, the reader will recall, is to aid the selection of measures of system performance/effectiveness. Thus, only if the STM application leads to practical and comprehensive measures can one conclude that the STM is a viable component of the overall measurement process.

The advantages in choosing the performance element of surveillance were that, first, it is a requirement common to many military human-machine systems and, second, it entails many potentialities, processes, and products of performance and is subject to the influence of many environmental and constraining factors. Thus, as a test of the measures-derivation process, it permitted a wide variety of system taxa to be included and offered the possibility of producing measures relevant to many system applications.

Figure 17 displays the Carrier Team System taxa associated with the "surveillance" performance element. On the Objectives Level of system description, these taxa include:

- The basic capability (potentiality) of surveillance.
- The process of sector surveillance, for both air and ground sectors.
- The product of threat detections (for which surveillance is a prerequisite).
- The physical and climatological environment.
- Surveillance constraints.
- Threat constraints (the nature of the threats, and the tactical response required, may affect how the system performs surveillance).

	POTENTIALITIES	PROCESSES	PRODUCTS	ENVIRONMENT	CONSTRAINTS
OBJECTIVES	Possess Capability: Surveillance (1.1) Capability	Perform Process: Air/Ground Sector (2.2) Surveillance Processes	Output Product: Threat (5.2) Detections	In the Presence of: Rolling Terrain (3.1) Rural/Agricultural (3.2) Indigenous Obstacles(3.3) Summer Fair (3.4) Weather	In Compliance with: Surveillance (4.1) Constraints Threat (4.5) Constraints
FUNCTIONAL PURPOSES	Apply Capability for: Surveying Sector (1.1.1) Detecting Targets (1.1.2) Acquiring Targets (1.1.3)	Apply Processes to: Locate Signatures (2.2.1) Locate Avenues (2.2.2) Locate Threats (2.2.3)	Apply Products to Provide: Enemy Locations (5.2.1) Intelligence Information (5.2.2) Tactical Decisions(5.2.3)	Performance Subject to: Hills, Valleys, Flat(3.1.1-1-3) Fields, Roads,(3.2.1-4) Farms, Forests, Stone Walls, Rocky Outcroppings, Marsh/Swamp (3.3.1-5) Trees, Trenches, Warm/Hot, Daylight, no precipitation, Good Visibility (3.4.1-4)	Performance Subject to: Continuous Surveillance (4.1.1) Likely Threat Observation (4.1.2) Appropriate Threat Neutralization (4.5.1)
CHARACTERISTICS	Accomplish Purpose with: Unaided Visual Surv.(1.1.1.1) Aided Visual Surv.(1.1.1.2) Visual Detection (1.1.2.1) IR Detection (1.1.2.2) Visual Viewing (1.1.3.1) IR Viewing (1.1.3.2) Visual Identifying (1.1.4.1) Tracking Moving TGT While Moving (1.1.5.1) Tracking Stationary TGT (1.1.5.2) Tracking Moving TGT While Stationary (1.1.5.3)	Accomplish Purposes with: Signature Detection (2.2.2.1) Signature Identification (2.2.1.2) Avenue Assessment (2.2.2.1) Avenue Classification (2.2.2.2) Threat Dection (2.2.3.1) Threat Identification (2.2.3.2) Threat Classification (2.2.3.3)	Accomplish Purposes with: Signature locations (5.2.1.1) Actual Threat Locations (5.2.1.2) What was Observed (5.2.2.1) How Many Observed (5.2.2.2) Where/When Observed (5.2.2.3) Actions by Enemy (5.2.2.4) Degree of Threat (5.2.3.1) System Capability (5.2.3.2) Threat to Mission (5.2.3.3)	Performance Subject to: All Characteristics of Environment Apply: Upslope: 250m, 8° Downslope: 1000m, 8° Flats: 1000m Fields: cultivated/ incultivated Roads: Secondary, light Duty, Trails Farms: Livestock, crops Forests: deciduous, coniferous, mixed Bypass Constraints for: walls, outcroppings, marshes, swamps, trees trenches Temperature: 27°-32°C Humidity: low-mod. Light: morning, sunny Climate: dry, dusty Visibility. clear, glare	Performance Subject to: Continuous Scan (4.1.1.1-2) Hatch Down (4.1.1.4) Train Surveillance (4.1.2.2) Minimum Exposure (4.5.1.2)

Figure 17. Carrier Team System Taxa Associated with "Surveillance" Performance Element

All taxa that "descend" from these on the Functional Purposes Level and the Characteristics Level also are included.

The numbers shown in parentheses in Figure 17 refer to the taxonomy codification scheme illustrated in Figure 16. They allow the links among the three levels of description to be indicated explicitly. For example, taxon 1.1.2.1 "descends" from taxon 1.1.2, which in turn "descends" from 1.1.

If the staff's actual purpose had been to devise and implement a plan for evaluating the performance/effectiveness of the IFV Squad (rather than simply testing the utility of an analytic procedure), a large-scale literature review would have been conducted at this point. The taxa arrayed in Figure 17 would have been used as search terms for accessing the body of published literature on human-machine systems measurement, with a view toward identifying measures, analytic methods, and other test procedures that previously were applied successfully to evaluate systems similar to the IFV Squad. Indeed, a major purpose behind development of the STM is precisely to facilitate such access to relevant literature and, ultimately, to impose an effective organization upon the published systems measurement literature. For purposes of this example, however, it was not deemed necessary to conduct a formal literature review. Instead, the staff members relied on their own system measurement experience with surveillance systems (especially those in the infantry and air defense artillery contexts) as the source from which measures relevant to the listed taxa would be drawn.

Figures 18, 19, and 20, respectively, depict the measures that are potentiality-oriented, process-oriented, and product-oriented. The first set of measures (Figure 18) are intended to answer questions about the basic capabilities for surveillance that the system possessed. The second set (Figure 19) answers questions concerning how the system performs its various surveillance activities. The third set (Figure 20) addressed questions concerning the results of those surveillance activities.

Each set of measures is organized in conformance to the STM's three levels of system description. The uppermost row in each figure contains only those measures associated with Objectives Level taxa. All of those measures are of the nominal variety. The second row is reserved for measures associated with Functional Purposes Level taxa; those include both nominal and relative measures. All lower rows deal with measures associated with Characteristics Level taxa. Those are strictly relative measures.

Measures are labelled with reference to the particular attribute (taxon) of performance on which they bear. Each such taxon is itself designated by a numeric-decimal label. Each measure associated with a given taxon is labelled by that taxon's numeric-decimal, with parenthetic alphabetic postscript. For example, three measures are identified in Figure 18 for the "Surveying Sector" taxon designated by 1.1.1 (a Functional Purposes Level taxon under the Performance Potentialities column). Those three measures are designated by 1.1.1(A), 1.1.1(B), and 1.1.1(C), respectively.

One important point that bears re-emphasis is that <u>all</u> measures listed in Figures 18, 19, and 20 focus on the system's performance of surveillance. Each measure derives from some particular system taxon, but the measure is concerned

5 b

OBJECTIVES	**Surveillance Capability** 1.1(A) Types of surveillance methods/mechanisms included in the system 1.1(B) Environments that can be surveyed by the system				
FUNCTIONAL PURPOSES	**Surveying Sector** 1.1.1(A) Kinds of sectors that the system can survey 1.1.1(B) Sector physical limits 1.1.1(C) Sector scan rates	**Detecting Targets** 1.1.2(A) Kinds of targets the system can detect 1.1.2(B) Methods/mechanisms of detection 1.1.2(C) Detection probabilities (function of time, target) 1.1.2(D) False alarm probabilities 1.1.2(E) Receiver operating characteristics 1.1.2(F) Detection time lags	**Acquiring Targets** 1.1.3(A) Kinds of targets the system can acquire 1.1.3(B) Methods/mechanisms of acquisition 1.1.3(C) Acquisition probabilities/given detection (function of time, target) 1.1.3(D) Acquisition time lags	**Identifying Targets** 1.1.4(A) Kinds of targets the system can identify 1.1.4(B) Methods/mechanisms of identification 1.1.4(C) Probabilities of correct identification/given acquisition 1.1.4(D) Identification time lags	**Tracking Targets** 1.1.5(A) Kinds of targets the system can track 1.1.5(B) Methods/mechanisms of tracking 1.1.5(C) Tracking rates 1.1.5(D) Tracking accuracy
CHARACTERISTICS	**Unaided Visual Surveillance** 1.1.1.1(A) Physical parameters of field of view 1.1.1.1(B) Amount of sector that can be covered 1.1.1.1(C) Unaided visual scan rates **Aided Visual Surveillance** 1.1.1.2(A) Physical parameters of field of view 1.1.1.2(B) Amount of sector that can be covered 1.1.1.2(C) Degree of visual enhancement 1.1.1.2(D) Aided visual scan rates **IR Sensor Surveillance** 1.1.1.3(A) Physical parameters of IR sensor field 1.1.1.3(B) Amount of sector that can be covered 1.1.1.3(C) IR sensor scan rates 1.1.1.3(D) Minimum temperature differential thresholds	**Visual Detection Ability** 1.1.2.1(A) Visual detection probabilities 1.1.2.1(B) Visual false alarm probabilities **IR Detection Ability** 1.1.2.2(A) IR detection probabilities 1.1.2.2(B) IR false alarm probabilities	**Visual Acquisition Ability** 1.1.3.1(A) Visual acquisition probabilities **IR Acquisition Ability** 1.1.3.2(A) IR acquisition probabilities	**Visual Identification Ability** 1.1.4.1(A) Probabilities of correct visual identification **IR Identification Ability** 1.1.4.2(A) Probabilities of correct IR identification	**Ability to Track Moving Targets, While Moving** 1.1.5.1(A) Tracking stability (function of own speed) 1.1.5.1(B) Maximum angular velocity limits 1.1.5.1(C) Maximum angular acceleration limits **Ability to Track Stationary Targets, While Moving** 1.1.5.2(A) Tracking stability (function of own speed) 1.1.5.2(B) Maximum angular velocity limits 1.1.5.2(C) Maximum angular acceleration limits **Ability to Track Moving Targets, While Stationary** 1.1.5.3(A) Maximum angular velocity limits 1.1.5.3(B) Maximum angular acceleration limits

Figure 18. IFV Surveillance: Potentiality-Oriented Measures

OBJECTIVES	**Air/Ground Sector Surveillance Processes** 2.2(A) Kinds of surveillance processes included in the system 2.2(B) Procedures employed to implement the surveillance processes		
FUNCTIONAL PURPOSES	**Locate Signatures** 2.2.1(A) Types of signatures to be located 2.2.1(B) Procedures used to locate signatures 2.2.1(C) Data acquired relevant to signature location 2.2.1(D) Data interpreted relevant to signature location	**Locate Avenues** 2.2.2(A) Types of avenues to be located 2.2.2(B) Procedures used to locate avenues 2.2.2(C) Data acquired relevant to avenue location 2.2.2(D) Data interpreted relevant to avenue location	**Locate Threats** 2.2.3(A) Types of threats to be located 2.2.3(B) Procedures used to locate threats 2.2.3(C) Data acquired relevant to threat location 2.2.3(D) Data interpreted relevant to threat location
CHARACTERISTICS	**Signature Detection** 2.2.1.1(A) Degree to which available signature detection data were actually acquired 2.2.1.1(B) Degree to which acquired data were correctly processed 2.2.1.1(C) Degree to which results were correctly interpreted **Signature Identification** 2.2.1.2(A) Degree to which available signature identification data were actually acquired 2.2.1.2(B) Degree to which acquired data were correctly processed 2.2.1.2(C) Degree to which results were correctly interpreted	**Avenue Assessment** 2.2.2.1(A) Degree to which available data on likely threat avenues were actually acquired 2.2.2.1(B) Degree to which acquired data were correctly processed 2.2.2.1(C) Degree to which results were correctly interpreted **Avenue Classification** 2.2.2.2(A) Degree to which available avenue classification data were actually acquired 2.2.2.2(B) Degree to which acquired data were correctly processed 2.2.2.2(C) Degree to which results were correctly interpreted	**Threat Detection** 2.2.3.1(A) Degree to which available detection data on threats were actually acquired 2.2.3.1(B) Degree to which acquired data were correctly processed 2.2.3.1(C) Degree to which results were correctly interpreted **Threat Identification** 2.2.3.2(A) Degree to which available threat identification data were actually acquired 2.2.3.2(B) Degree to which acquired data were correctly processed 2.2.3.2(C) Degree to which results were correctly interpreted **Threat Classification** 2.2.3.3(A) Degree to which available threat classification data were actually acquired 2.2.3.3(B) Degree to which acquired data were correctly processed 2.2.3.3(C) Degree to which results were correctly interpreted

Figure 19. IFV Surveillance: Process-Oriented Measures

OBJECTIVES	**Threat Detections** 5.2(A) Kinds of threats detected by the system 5.2(B) Kinds of threats not detected by the system 5.2(C) Kinds of false detections produced by the system		
FUNCTIONAL PURPOSES	**Enemy Locations** 5.2.1(A) Kinds of enemy locations identified correctly 5.2.1(B) Kinds of enemy locations not identified 5.2.1(C) Kinds of false enemy locations mis-identified 5.2.1(D) Numbers of enemy locations identified (for each kind) 5.2.1(E) Numbers of enemy locations not identified (for each kind) 5.2.1(F) Numbers of false enemy locations mis-identified (for each kind)	**Intelligence Information** 5.2.2(A) Kinds of intelligence information correctly compiled (from observation) 5.2.2(B) Kinds of intelligence information incorrectly compiled 5.2.2(C) Kinds of available intelligence information not compiled 5.2.2(D) Numbers of correct intelligence reports compiled 5.2.2(E) Numbers of incorrect intelligence reports compiled 5.2.2(F) Numbers of available intelligence reports not compiled	**Tactical Decisions** 5.2.3(A) Kinds of information (relevant to tactical decisions) that were correctly gleaned from observation 5.2.3(B) Kinds of information (relevant to tactical decisions) that were incorrectly gleaned from observation 5.2.3(C) Kinds of available information (relevant to tactical decisions) that were not observed 5.2.3(D) Amount of correctly observed tactical decision input data 5.2.3(E) Amount of incorrectly observed tactical decision input data 5.2.3(F) Amount of available tactical decision input data not observed
CHARACTERISTICS	**Signature Locations** 5.2.1.1(A) Percentage of actual signatures located 5.2.1.1(B) Ratio of false signatures located to true signatures located 5.2.1.1(C) Distribution of distances at which actual signatures were located 5.2.1.1(D) Distribution of exposure times at which actual signatures were located 5.2.1.1(E) Distribution of Distances at which false signatures were located 5.2.1.1(F) Distribution of exposure times at which false signatures were located **Actual Threat Locations** 5.2.1.2(A) Percentage of actual targets located 5.2.1.2(B) Ratio of false targets located to true targets located 5.2.1.2(C) Distribution of amounts of signature displayed by actual targets that were located 5.2.1.2(D) Distribution of amounts of signature displayed by actual targets that were not located 5.2.1.2(E) Distribution of amounts of signature apparent signature associated with false target detections 5.2.1.2(F) Distribution of distances at which actual targets were located 5.2.1.2(G) Distribution of exposure times at which actual targets were located 5.2.1.2(H) Distribution of distances at which false targets were located 5.2.1.2(I) Distribution of exposure times at which false targets were located	**Information on What Was Observed** 5.2.2.1(A) Numbers of correctly observed identification ("what") data items 5.2.2.1(B) Numbers of incorrectly observed identification data items 5.2.2.1(C) Numbers of available identification data items not observed **Information on How Many Were Observed** 5.2.2.2(A) Numbers of correctly observed quantification ("how many") data items 5.2.2.2(B) Numbers of incorrectly observed quantification data items 5.2.2.2(C) Numbers of available quantification data items not observed **Information on Where & When Observations Were Made** 5.2.2.3(A) Numbers of correctly observed spatio-temporal ("where/when") data items 5.2.2.3(B) Numbers of incorrectly observed spatio-temporal data items 5.2.2.3(C) Numbers of available spatio-temporal data items not observed **Information on Enemy Actions Observed** 5.2.2.4(A) Numbers of correctly observed enemy action data items 5.2.2.4(B) Numbers of incorrectly observed enemy action data items 5.2.2.4(C) Numbers of available enemy action data items not observed	**Tactical Decisions Regarding Assessment of Degree of Threat to System** 5.2.3.1(A) Numbers of correctly observed system threat data items 5.2.3.1(B) Numbers of incorrectly observed system threat data items 5.2.3.1(C) Numbers of available system threat data items not observed **Tactical Decisions Regarding Assessment of System's Capability vis-a-vis the Threat** 5.2.3.2(A) Numbers of correctly observed system capability data items 5.2.3.2(B) Numbers of incorrectly observed system capability data items 5.2.3.2(C) Numbers of available system capability data items not observed **Tactical Decisions Regarding Assessment of Degree of Threat to Mission** 5.2.3.3(A) Numbers of correctly observed mission threat data items 5.2.3.3(C) Numbers of available mission threat data items not observed

Figure 20. IFV Surveillance: Product-Oriented Measures

only with the interaction of that taxon with surveillance. If some other aspects of system performance (e.g., "Squad Command and Control," "Communications") had been under study, the relevant taxa might have included some items that are similar to those listed for "surveillance." However, even if the taxa were identical for the several performance aspects, different measures would most likely have been derived because of differing measurement purposes.

Some examples can clarify the preceding point. One of the product-oriented taxa associated with surveillance is "Tactical Decisions" (item 5.2.3, on the Functional Purposes Level in Figure 20). The association stems from the fact that surveillance is a principal source of input for IFV Squad tactical decisions. If an analyst wishes to undertake a comprehensive assessment of the system's performance of surveillance, one issue that must be addressed, therefore, is "How well does the system's surveillance provide input to its tactical decisions?" It is precisely that issue that is addressed by the measures listed under "Tactical Decisions" in Figure 20. The reader will note that those measures have nothing directly to do with the kinds of tactical decisions made, with the correctness of those decisions, with the decision-making process itself. The measures are concerned only with the kinds and quantities of tactical decision input data supplied or overlooked by the surveillance process. Those measures are applied in the context of tactical decisions, but they remain focused on surveillance.

Suppose for the moment, however, that measures were being sought not for the "Surveillance" performance element, but rather for "Squad Command and Control." Tactical decisions would also be included in the set of taxa associated with that performance element because the formulation of tactical decisions is an integral part of the exercise of command. Now, however, the key question would be, "How well does the system formulate its tactical decisions, given the information available?" The measures needed to address that question would focus on the kinds of decisions made, the decision algorithms used, the volumes of decisions made, their correctness, their timeliness, etc. In short, different sets of measures might derive from a common system taxon, depending upon the performance element of interest.

Another example in this same context may be based on the measures listed (in Figure 20) for the taxon, "Information on What Was Observed" (item 5.2.2.1, on the Characteristics Level). Those measures address the system's performance in observing data bearing on the identification of threats, threat signatures, etc. The issues of interest to the assessment of surveillance are how much of the available data was observed, how much was missed, how much was observed inaccurately, etc. None of these measures are at all concerned with what is done with the data after they are collected through surveillance. However, if one were studying the "Communications" performance element, this same taxon would be involved, but the appropriate measures then would focus on how much of the information on threat identification was transmitted to appropriate recipients (e.g., Platoon HQ), how quickly the information was transmitted, how accurately, etc. Furthermore, if one were interested in the "Weapons Operation" performance element, once again the same taxon would be included. But in that case, the measures of the threat identification information would deal with how well that information was used in the selection of weapons, ammunition, fire rates, etc.

The basic point, as has been mentioned before, is that the taxa are abstractions of measures. The concrete specification of the measures they represent depend on exactly which facet or element of the system's performance is being studied.

The measures hierarchy depicted in Figures 18, 19, and 20, of course, is an idealized set. That is, no attempt has been made to determine the feasibility of using any of the measures, or to eliminate those that may require data that cannot be obtained under realistic circumstances. That "weeding out" activity properly belongs at a later stage in the overall measurement process. The purpose of the taxa is to guide the analyst in identifying and organizing a set of measures that, if they can be used, would answer all the research questions at hand. The taxa themselves shed little or no light on the practicality of those measures.

There is no conclusive test or set of standards that can be used to judge the merits of the "Surveillance" measures hierarchy. The true merits of any measure can be known only when the measure is actually employed under the intended circumstances. This is especially true in this case, since no rigorous search of the literature nor any appeal to subject-matter experts was involved in the construction of this measures set. Nevertheless, while acknowledging that this set could certainly be improved, the measures themselves appear intuitively to be well suited to assess the IFV Squad's performance of surveillance. The measures would allow the analyst to proceed in a careful and logical step-by-step fashion. Applied in the proper sequence, they would address the following kinds of questions:

- What capabilities does the IFV Squad possess in the area of surveillance?
- What surveillance capabilities did the system actually use in this particular measurement application?
- How were these capabilities affected by the environmental and other circumstances that pertained to this particular measurement application?
- What procedures did the system actually use to apply its surveillance capabilities?
- How did these procedures differ from the prescribed surveillance procedures?
- How did the environmental and other circumstances affect the surveillance procedures?
- For what specific applications were the surveillance procedures conducted?
- Was sufficient and appropriate information or other input supplied to those applications through surveillance?
- What specific deficiencies were found in the information/input provided by surveillance?

Achieving the ability to answer questions such as these in every analytic application would, in the opinion of the authors, constitute substantial progress in the state-of-art of human-machine systems measurement. In this specific instance at least, the STM has produced a measures set that apparently is structured around the right kinds of research questions, and that possesses the logical sequential organization required to address those questions. If nothing else, the authors suggest that this result justifies continued efforts to improve and apply the STM, and the overall measurement process model as well.

E. "Final Revision" of the STM

Findings of the IFV Application pertaining to Taxonomization

The trial application using the "first revision" STM focused on the two major subsystems of the IFV Squad, viz., the Carrier Team Subsystem and the Crew Compartment Team Subsystem. Summing across the three levels of system description and the six contextual aspects of measurement, several hundred system populations (taxa) were identified for each of those two subsystems. Had the application been carried out to its final conclusion, similar taxa would have been identified for the platoon suprasystem and for the various postulated threats (collateral systems). Also, a merger of the Carrier Team and Crew Compartment Team taxonomies would have been created to document the populations of interest to the IFV Squad in toto. However, it was apparent that the trial application, including the derivation of a sample hierarchy of measures, had been carried out to an extent sufficient to permit conclusions to be drawn concerning the STM's utility and needs for further revision. These conclusions are listed below.

1. THE THREE DIFFERENT ASPECTS OF PEFORMANCE PROVIDE A CONVENIENT AND PRACTICAL MEANS OF ANALYZING HOW WELL A SYSTEM WORKS.

   A triad of performance aspects, i.e., potentialities (System Definition), processes (Mission Requirements), and products (Performance Requirements) proved to be a workable and helpful concept for identifying system taxonomies and, ultimately, measures of effectiveness/performance. It is true that the taxonomies that emerged under those three columns had much in common. All three encompassed system populations organized around such jobs as surveillance, movement, communication, weapons operation, and the like. However, although their taxa exhibited similar organizing principles, the taxa themselves differed importantly, if subtly, from one column to the next. Each column disclosed taxa that suggested some very useful appearing measures of effectiveness/performance. No one column, nor any two of the three, produced all of the measures that seemed appropriate. All three appear to be necessary for a complete assessment of a system's value.

   There is really nothing surprising in this result. Most researchers agree that a product evaluation alone often cannot suffice to judge the absolute or relative merits of a system. Despite the common notion that nothing matters except "results," or the "bottom line," it usually is necessary to consider how the system operates (process measurement) and what it is capable of doing (potentiality measurement) to obtain a full picture of its worth. This is particularly true in cases where it is very difficult or virtually impossible to obtain product-oriented measures, e.g., when the system of interest is at an early stage of development or is of a type (such as nuclear weapon systems) whose products cannot be delivered for test purposes. On the other hand, it would be equally inappropriate to exclude all product-associated variables from the system measurement scheme and concentrate exclusively on measures of process and potentiality. No matter how satisfactory a system's capabilities and procedures may appear to be, at some point it becomes necessary to ascertain whether it does, in fact, produce the goods or services desired. In sum, the overall scheme of human-machine system measurement must include adequate provision for all three aspects of system performance. Based upon its trial application to the IFV, the STM appears to provide adequately for that requirement.

2. THE THREE LEVELS OF SYSTEM DESCRIPTION INTERACT WITH THE THREE ASPECTS OF PERFORMANCE TO PRODUCE SETS OF MEASURES OF EFFECTIVENESS/PERFORMANCE.

When the STM concept was first formulated, one of its fundamental postulates was that two general levels of measurement are relevant to the study of any human-machine system. The first level encompasses <u>nominal</u> measures of effectiveness/performance, i.e., measurement <u>categories</u> that do not relate to one another in any inherent order. The classic example of nominal measurement is the categorization of fruit as "apple" or "orange." In no meaningful sense is an orange greater or less than an apple. The second level of measurement is termed <u>relative</u>, and encompasses the familiar measurement scales called <u>ordinal</u>, interval, and ratio, all of whose measurement categories do possess an orderliness (in the comparative sense). A driving principle behind the STM concept is that, for any particular aspect or component of a system's performance, there exists a set of related measures, including both nominal and relative, that can be structured in a logical sequence. That is, for any of the system's potentialities, processes, or products it must be possible to identify a series of measures, beginning with the nominal and evolving toward the relative, all of which can provide helpful information concerning how well the system produces the product, carries out the process, or possesses the potentiality in question. Moreover, that series of measures must correspond directly to the system populations (taxa) to which the system belongs by virtue of that particular potentiality, process, or product. Indeed, it is another basic premise of the STM concept that the taxa <u>are</u> the measures, at least in the abstract. That is, the taxa are dimensions which provide the initial specification of, or basis for, defining useful measures. The three levels of system description were incorporated into the STM to provide a mechanism for extracting the measures set. All three levels would address the same issues concerning the system's performance. However, the perspective of the Objectives Level was expected to disclose nominal measures pertaining to the performance element in question, on a relatively "macroscopic" scale. The Functional Purposes level was expected to provide a mixture of both nominal and relative measures, but focused on the major details of that performance element. The Characteristics Level would provide relative measures, pertaining to the "microscopic" details of the performance element.

The IFV trial application showed that the three levels of System Description do indeed play their intended roles in identifying measures sets. The progression of perspectives for dealing with the various aspects of system performance afforded by the three levels of System Description potentially can yield an MOE hierarchy that provides the expected sequence of nominal-to-relative measures. This is illustrated in Figure 21, which interprets a portion of the measures set for the IFV performance potentiality "Providing Surveillance," previously shown in Figure 18.

3. THE TWO GENERAL CATEGORIES OF FACTORS IMPEDING OR OTHERWISE INFLUENCING SYSTEM PERFORMANCE PROVIDE WORKABLE MEANS OF RELATING THE MEASURES TO THE MEASUREMENT PURPOSE AT HAND.

As previously described, there are two broad classes of factors, associated with any particular measurement purpose, that may impede or otherwise affect the system's performance. Those are the factors that occur naturally and are beyond the arbitrary control of human agents, and the factors that occur because of a conscious human decision or intervention. The former have been termed "Environment Specification;" the latter, "General Constraints." The experience of the IFV trial application suggests that it is relatively easy and straightforward to identify these factors, on all three levels of system description. However, this can be done only after all elements of the system's performance have been identified (i.e., the various potentialities, processes, and products, their applications, and the ways in which they can be achieved). The impeding/influencing factors drawn from the environment, tactical doctrine, and other sources can be discerned only after one knows what elements of performance are relevant, and analyzes those elements to determine how they might be impeded. Thus, the two contextual aspects of measurement that have been labeled "General Constraints" and "Environment Specification" should be retained in the STM, but they should be addressed only after the performance-based taxonomies have been identified.

4. PERFORMANCE CRITERIA DO NOT FALL WITHIN THE PURVIEW OF THE SYSTEM TAXONOMY MODEL

The attempt to identify taxa based on performance criteria (as distinct from performance elements) added nothing of substance to the trial application. It was noted above that taxa derived from

	Relevant Taxa	Measures
OBJECTIVES LEVEL (Discrete Performance Elements)	"The IFV belongs to the population of systems that are capable of providing surveillance"	• Types of surveillance methods/mechanisms included in the system • Media in which the system can provide surveillance ⋮
FUNCTIONAL PURPOSES LEVEL (Applications of the Discrete Performance Elements)	"The IFV belongs to the population of systems that provide surveillance in order to have the capability of detecting targets"	• Types of targets that the system can detect • Target detection probabilities ⋮
	"The IFV belongs to the population of systems that provide surveillance in order to have the capability of surveying sectors" ⋮	• Kinds of sectors in which surveillance can be provided • Maximum sector physical limits • Sector scan rates ⋮
CHARACTERISTICS LEVEL (Ways in Which the Applications of the Performance Elements Can Be Achieved)	"The IFV belongs to the population of systems that can survey sectors by means of aided visual optics"	• Degree of image magnification • Degree of image intensification • Aided optics viewing angles ⋮
	"The IFV belongs to the population of systems that can survey sectors by means of IR Sensor" ⋮	• Signal-to-noise ratios • Effective Range • Sensitivity ⋮

Figure 21. Partial Set of Measures
(Showing the progression from primarily nominal to primarily relative measures)

performance elements (potentialities, processes, or products) are actually abstractions of measures of those performance elements. Similarly, it became evident that taxa derived from performance criteria are abstract versions of measurement criteria. However, they proved to be too abstract to be of practical value. The criterion-based system populations that emerged from the IFV trial application consisted essentially of such terms as "appropriate," "timely," "accurate," "complete," "efficiently," "quickly," "successfully," etc. Although these terms certainly express universally accepted qualities of "goodness," they also certainly do not provide the degree of specificity that an analyst needs to evaluate a system's performance. That specificity can only be achieved after the actual hierarchy of measures has been extracted from the taxa. In sum, selection/derivation of performance criteria obviously remains an element of the overall process of system measurement, but it does not fall within the segment of that process that is of concern to system taxonomy modeling.

5. SPECIFIC, WORKABLE GUIDELINES FOR IDENTIFYING TAXONOMIES RELEVANT TO A PARTICULAR SYSTEM AND A PARTICULAR MEASUREMENT PURPOSE CAN BE DEVELOPED.

Perhaps the most significant result of the IFV trial application was the fact that concrete guidelines for the taxonomization process emerged. Once most of the system populations associated with the IFV's performance elements and levels of system description had been identified, organizing principles for those populations began to become evident. The recognition of those principles allowed the staff to accelerate the process of identifying the remaining relevant taxa, which in turn helped to clarify the principles further. As expected, then, the IFV trial application proved to be an excellent and fruitful taxonomization learning experience. Ultimately it was discovered that the organizing principle for any of the STM's "cells" (intersections of levels of System Description with measurement contextual aspects) could be described as an open-ended statement, augmented by a series of specific analytic questions. The open-ended statement expresses the "common theme" that binds together the entire set of system populations associated with the measurement aspect and level of system description in question. For example, the population-defining statement for the "cell" corresponding to System Definition on the Objectives Level of description is:

"The system must be capable of ..."

That statement can be completed by a list of discrete performance potentialities belonging to the system of interest. The list, collectively, defines the full range of capabilities belonging to that system. Each entry in the list defines a unique population of systems to which the system of interest belongs. For the IFV squad, the list that emerged in this particular "cell" was:

- providing surveillance
- conducting weapons fire

- providing squad command and control
- providing transportation
- providing communications
- providing squad protection

The analytic questions associated with a particular "cell" serve to clarify the population-defining statement, and provide means of identifying the taxa belonging to that "cell." The questions associated with the "cell" discussed in the above example are:

- "What must this system be capable of doing or providing?"

- "What kinds of services must it be able to provide?"

- "What needs is this system supposed to fulfill?"

- "For a military weapons system: what are the capabilities that this system must have in order to move-shoot-communicate?"

The above questions are intended to be neither mutually exclusive nor collectively exhaustive. They simply represent different convenient ways of exploring a system's potentialities. Similar sets of questions emerged as means of exploring its processes, products, and impeding factor All of these questions were derived in the context of the IFV, but they probably are suitable for commencing the taxonomization process for most human-machine systems. As other applications of this concept are completed, additional useful analytic questions undoubtedly will emerge. In this sense, one expects that the usability of the STM will increase adaptively the more that it is used. It is for this reason that the title of this section refers to the STM's "final" revision in quotation marks. The revision process actually never will reach a final state since every system measurement application using this model will contribute at least incrementally to every succeeding measurement application. Indeed, that is one of the basic reasons why the STM concept was first formulated.

Conclusions and "Final Revision"

The findings of the IFV trial application led to substantial further revision of the STM. The model now includes five (rather than 6) columns; "Performance Criteria" no longer is a basis for taxonomization, but rather is relegated to a later stage of the overall measurement process. Of the five columns, three are oriented toward performance-based taxonomies. These are termed "Performance Potentialities, Processes, and Products." Those labels replace the earlier, less descriptive designations "System Definition," "Mission Requirements" and "Performance Requirements," respectively. The other two columns continue to be labeled "Environment Specification" and "General Constraints." They are oriented toward condition-based taxonomies, i.e., the circumstantial and situational factors that must be reflected in the process of measurement. Those two are the right-most columns in the STM, reflecting the fact that their taxonomies can be identified only after the performance-based taxonomies have been determined.

Figure 22 depicts the revised version of the STM, including its updated taxonomization guidelines. This is the "Final Revision" of the STM insofar as the present project scope of work is concerned. However, the taxonomization guidelines undoubtedly will be further improved as additional applications to other systems occur.

The ultimate conclusion of the IFV trial application is that the STM is a practical tool for identifying the hierarchy of measures of performance/effectiveness for any human-machine system in any particular measurement application. Although this first major application of the STM was exceedingly laborious and time-consuming, substantial progress was made toward developing specific taxonomization procedures and guidelines. Future applications, therefore, should proceed much more efficiently, and lead to increased utility of the STM.

	PERFORMANCE POTENTIALITIES	PERFORMANCE PROCESSES	PERFORMANCE PRODUCTS	ENVIRONMENT SPECIFICATION	GENERAL CONSTRAINTS
OBJECTIVES	"The system must be capable of..." What must this system be capable of doing or providing? What kinds of services must it be able to provide? What needs is this system supposed to fulfill? For a military weapons system: What are the capabilities needed to move-shoot-communicate?	"The system must carry out the following activities..." What jobs are required of this system? What procedures are involved in this mission? What assignments does this system receive to support higher command?	"The system must produce..." What products must the system deliver in the course of this mission? What goods or services must it output? What results are being sought?	"The system must operate under the following conditions..." What naturally occuring factors may affect the system's work? What elements of the environment might affect the system's potentialities, processes, or products?	"The system must operate under the following restrictions..." What factors affecting the system's work have been imposed by doctrine or other intervention?
FUNCTIONAL PURPOSES	"This particular capability must allow the system to be able to..." What are the purposes to which each potentiality might be applied? How is the system supposed to use its capabilities? Where specifically do its needs arise?	"The reasons for carrying out this particular activity are..." What are the purposes for doing each job? Why have the assignments been given? What are the reasons for implementing the procedures?	"This particular product will be used by the system to..." What benefits can be derived from the results? How will the system use what it produces?	"The system's purposes must be satisfied in the face of..." What environmental factors might affect the applications of the system's potentialities, processes, or products?	"The system's purposes must be satisfied in the face of..." How might the imposed factors influence the purposes to which the system's potentialities, processes, or products may be put?
CHARACTERISTICS	"To satisfy this particular application, the system must have the ability to..." What specific abilities are needed to serve each purpose? What different capabilities can be brought to bear on each application?	"The tasks required to satisfy the particular purpose are..." What steps must the system take in order to accomplish the applications? In what different ways can the system carry out its assignments?	"To achieve that benefit, the system first must produce..." What milestones have to be achieved to realize the benefit? What intermediate goods and services are needed to deliver the finished product? What are the stepping stones toward the desired output?	"The constituent abilities, procedures, and milestones may be affected by..." How might the environment impact on the abilities, procedures, or intermediate results? What are the specific influencing factors in the environment? How should the system respond to those factors?	"The constituent abilities, procedures, and milestones may be affected by..." How might the imposed factors impact on the abilities, procedures, or intermediate results? How should the system respond to those factors?

Figure 22. "Final Revision" STM, including Revised Taxonomic Guidelines

III. STM UTILIZATION PROCEDURES

The procedures for using the Systems Taxonomy Model evolved (as did the STM itself) from the trials and errors of numerous system taxonomization exercises, beginning with very simple systems and culminating with the IFV Squad application. A major component of those procedures, of course, is the set of taxonomization guidelines, the latest version of which was shown in Figure 22. Theoretically, those guidelines are the STM utilization procedures. That is, one simply needs to follow the guidelines for any particular cell in the STM until all relevant system populations belonging to that cell have been found, then move on to another cell, and then to another, until finally all cells in the matrix have been filled. As a practical matter, however, some preparation certainly is needed before one can attempt to apply any of the guidelines. Also, experience dictates that it is best to start working on certain specific cells, and to move on to the others in a particular sequence. Experience further shows that certain combinations of cells should be addressed in an iterative, interactive fashion so that their taxa are identified in parallel.

These practical considerations are described in detail in the utilization procedures outlined below.

A numeric or other suitable ordering scheme should be used to help organize the taxa into logically associated groups.

The STM is not only supposed to aid the analyst in identifying the system populations to which a system of interest belongs, but also to aid in organizing those populations to support development of a logically structured hierarchy of measures of performance/effectiveness. The hierarchy depicted for "Surveillance" in Figures 18, 19, and 20 in the previous section provides a good illustration of a logical structure. Those measures are arrayed in a descending sequence of increasing specificity, precisely because they are grouped under taxa that have exactly that relationship to one another. When the project staff set out to assemble that measures set, they were greatly assisted by the fact that the "links" among taxa were explicitly exhibited. Thus, once it was determined which taxa on the Objectives Level of system description were relevant to "Surveillance," it was immediately evident which taxa on the Functional Purposes Level and Chracteristics Level were also relevant. A numeric ordering scheme tied the three levels of taxa together explicitly.

The scheme that was adopted employs a hierarchical decimal notation. The first (leftmost) digit indicates the particular system contextual aspect (i.e., STM column) to which the designated taxon belonged. Originally, this scheme permitted the first digit to take on the values 1 through 6, corresponding to the six columns previously included in the STM. Since then, the column/contextual aspect labeled "Performance Criteria" has been removed from the STM, and the sequence and nomenclature of the remaining columns have been modified. In the current taxonomy ordering scheme, the leading digit can take on any value from 1 to 5, where each digit has the following significance:

1. Designates taxa oriented toward performance potentialities.
2. Designates taxa oriented toward performance processes.
3. Designates taxa oriented toward performance products.
4. Designates taxa oriented toward environment specification.
5. Designates taxa oriented toward general constraints.

Any taxon belonging to the Objectives Level of system description is designated by a two-digit number of the general form X.Y, where X has the value 1 through 5 (as explained above) and Y has the value 1 or greater. The "Y" digit simply indicates the position of that particular taxon in that particular cell. For example, a taxon labeled 2.3 would be the third one listed in the cell corresponding to the Performance Processes column (column number 2) on the Objectives Level of system description; a taxon labeled 1.4 would be the fourth entry in the Performance Potentialities cell on the Objectives Level.

As repeatedly noted, taxa on lower levels of system description "descend" from taxa found on the Objectives Level. A principal purpose of the decimal notation is to make this top-to-bottom relationship explicit. Thus, any taxon found on the Functional Purposes Level of system description is designated by a three-digit number of the general form X.Y.Z, where:

> X.Y is the designator of the Objectives Level taxon from which this Functional Purposes Level taxon "descends."
>
> Z is the designator of the position that particular taxon occupies in the list of those "descending" from the X.Y Objectives Level taxon.

Obviously, the X.Y.Z taxon also belongs to column "X" in the STM, but is placed on the Functional Purposes Level rather than the Objectives Level.

Similarly, any Characteristics Level taxon is assigned a four-digit number, e.g., X.Y.Z.N, where X.Y.Z is the label of its "originating" Functional Purposes Level taxon and N is its own sequence number. Those taxa are arrayed on the lowest row of the STM, and in column "X".

Use of this or some other suitable ordering scheme greatly facilitates extraction of the taxa needed to generate any given measures hierarchy. The more complex the system is, the more helpful it is to have such a scheme. But even relatively simple systems tend to associate with fairly large sets of system populations; so an analyst almost always will find it worth the effort to include an ordering scheme in the taxonomization process.

> <u>All available system documentation should be examined before any attempt is made to identify and organize the system taxonomy.</u>

This is a fairly obvious procedural step, but it is important enough to warrant explicit mention. The analyst should insure that he or she has acquired the fullest possible knowledge of the system being studied before beginning the taxonomization process. Otherwise, the danger will exist that some elements of system performance will be overlooked in the analysis.

The kinds of documentation that proved very helpful in the IFV Squad trial application were the System Specifications, Materiel Needs Document, and System Task Descriptions. Previous IFV test plans and test reports also would have been accessed if a true, full-scale measurement application had been intended. Caution, of course, must be exercised in reviewing previous test plans and reports to acquire inputs for future performance measurement. There is a natural tendency to ascribe validity to anything that has been used or done in the past. The fact that a particular measure of performance was used in a previous test may lead a careless analyst automatically to include that measure in future test plans. Similarly, a measure previously rejected or excluded from prior applications may not receive the consideration it deserves when a new application is being prepared. The STM concept originally was formulated in response to a need to impose a systematic orderliness on the process of measures selection, to avoid the mistakes of the past. Previous test documents are a valid and essential source of input for system taxonomization, but they must be reviewed with a healthy skepticism.

Other helpful sources for acquiring fuller knowledge of the system being studied would include discussions with subject-matter experts (system designers, fabricators, and operators) and, not to be overlooked, documentation on the system or systems which the system of interest is supposed to replace. Few emerging systems provide radically new potentialities, processes, or products. Usually, they only offer (or promise) better performance. Thus, a basic idea about what should be expected of the system can be gleaned from a review of what is provided by the systems that currently do the jobs in question. Some inputs for the IFV taxonomization, for example, were obtained from the staff's knowledge of the M113 and its derivatives (such as the Improved TOW Vehicle).

The measurement application should be defined and described in detail before the taxonomization process begins.

The scope of a system taxonomization exercise does not necessarily (or usually) extend to all of the potentialities, processes, and products that constitute a system's performance under all circumstances. Rather, the scope is limited to those elements of performance, and the factors that influence them, that come into play in a given measurement application. The STM, after all, is definitely applications-oriented.

Definition and description of the measurement application are especially necessary for the identification of relevant taxa associated with Environment Specification (column 4) and General Constraints (column 5). Many systems are expected to perform under a wide variety of environments and constraints; so the total numbers of taxa that potentially could be included in those columns are huge. The application at hand must be clearly specified at the outset if those "condition-oriented" taxa are to be limited to a manageable set.

Preparation of a detailed description of the measurement application can be a fairly time-consuming task, resulting in an appreciable volume of documentation. Even for the limited IFV trial application, the staff found that it was necessary to prepare a comprehensive mission scenario, complete with maps, time-lines, etc. Without this preparatory step, however, key inputs to the taxonomization process would not have been available.

The taxonomization process should proceed column by column, working from left to right through the STM matrix.

Very simply, one starts by identifying all taxa associated with performance potentiality, moves on to identify all that are associated with performance processes, and then proceeds to identify all associated with performance products. Only then does the analyst examine and organize the "conditions-oriented" taxa associated with the environment and the imposed constraints.

This procedural step is rooted in the concept of performance as a logical sequence of:

- What can be done by the system.
- How it actually does it.
- What actually results from doing it.

Thus, it is reasonable to begin by identifying basic capabilities, then the ways in which those capabilities are applied, and finally the outcomes realized from their applications. Once all of these elements of performance are known, one can examine the circumstances and conditions under which they are supposed to exist.

Once an Objectives Level taxon is identified, its derivatives on the two lower levels should immediately be identified.

It might seem logical to attempt first to identify all taxa (in a particular column) that belong on the topmost (Objectives) Level of system description. Then, once the analyst is satisfied that he or she has accomplished that milestone attention could move on to the Functional Purposes Level, and remain there until all of those taxa have been identified. Finally, work could focus exclusively on the Characteristics Level. If this approach were followed, taxa (and measures sets) would emerge in a sequence corresponding to the natural evolution of systems and research issues. That is, the first sets of taxa identified would view the system as a "black box" or basic concept, and would lead to nominal measures compatible with the fundamental research issues generally associated with a system's conceptual stage of development.

The logic sketched above is quite compelling, and the taxonomization sequence it suggests was in fact attempted at the outset of the IFV trial application. However, it proved to be difficult to apply in practice. The staff found it conceptually much easier to focus on some particular element of performance and to stay with that element until it was completely described at all levels of detail. That is, it was found to be more effective to proceed as follows:

- Identify a taxon on the Objectives Level.
- Immediately identify a derivative taxon on the Functional Purposes Level.
- Immediately identify a derivative taxon on the Characteristics Level.
- Continue identifying derivative Characteristics Level taxa until no more can be derived from that Functional Purposes Level taxon.

- Identify another derivative Functional Purposes Level taxon, and immediately identify all of its derivative Characteristics Level taxa.

- Repeat the preceding step until no more Functional Purposes Level taxa can be derived from the original Objectives Level taxon.

- Identify another Objectives Level taxon and repeat the entire process. Continue until no more Objectives Level taxa can be found.

Of course, if the system under study were at a very early stage of development (e.g., concept definition stage), not all of its Characteristics Level or even Functional Purposes Level taxa might be identifiable. In that case, the procedure just outlined might be truncated.

The chief advantages found with this procedure were twofold. First, the train of thought was simply easier to keep on track when one continued to focus on a specific element of performance. By staying with a given element until all of its associated taxa had been found, it was less likely that subtle issues or aspects of that element would be overlooked. Second, the iterative cycling among the three levels of system description often helped to clarify the taxa that emerged. In many cases, the search for lower level derivative taxa produced refinements of their upper level origins. Sometimes, for instance, the staff realized that an Objectives Level taxon had not been defined with the degree of precision needed to allow lower level populations to be identified. In essence, the attempt to identify Functional Purposes Level taxa provided a means of assessing the thoroughness with which Objectives Level taxa had been specified. Likewise, the search for derivative Characteristics Level taxa served as a check on the Functional Purposes Level entries.

> Once all apparent taxa belonging to a particular cell have been identified, the analyst should attempt to discern and document the principles underlying the organization of those taxa.

The guidelines associated with each cell in the STM exist to aid the analyst in identifying what populations of systems should be included in that cell to help select measures for some particular system and measurement application. Those guidelines are nothing more, or less, than ways of looking at the system in question so as to extract a particular set of its population memberships. The guidelines are applied versions of principles for organizing or grouping together a particular set of taxa. Each guideline says, in effect, "find all of the taxa associated with the system of interest that share this particular attribute, quality, feature, etc.; those comprise the taxonomy that belongs to this cell." For one cell, the key organizing feature might be "the uses of a particular capability"; for another cell, it might be "the intermediate goods or services needed for delivery of a particular product." Whatever the attribute or feature may be, it has to be expressed in terms that are clearly understood by the analyst whose task it is to find the taxa. Unless the analyst understands what he or she is searching for, he or she is liable to find the process of taxonomization to be very laborious, and copious errors are liable to be made. The clearer the guidelines, the easier will be the taxonomization process.

The problem is that any set of descriptive words concerning an organizing feature or attribute is likely to be less applicable to some human-machine systems than to others. Sometimes, for example, an analyst might deal with the sort of system in which "intermediate goods and services" are not very easy to define. Indeed, the usual concept of goods and services might be foreign to the system in question. This is not to say that there exist no taxa associated with that system that properly belong to the cell usually organized around "goods and services." Rather, it simply means that the organizing concept embodied in "goods and services" requires an alternate verbal expression in order to be applicable to that system. It might, for instance, be easier for the analyst to discern taxa associated with "milestones" that need to be achieved in order to derive benefit from a particular system product, or the analyst might find the notion of "stepping stones" easier to grasp in the context of that system.

The reader might be starting to suspect that an unwarranted amount of attention is being paid here to a purely semantic issue. If all that is being said is that the guidelines need to incorporate some synonyms for clarity, then why not simply list those synonyms and be done with it? But the issue is not quite so simple. Whenever any concept is put into words, the concept becomes clouded by the connotations of those words. No two synonyms have exactly the same connotation. Thus, each alternate expression (or guideline) for identifying/organizing taxa for a given cell conveys slightly different (and always at least slightly distorted) information to the analyst. It is possible that, if the analyst is presented with a wide variety of alternate expressions, formed by virtually all combinations of all conceivable synonyms, he or she may be able to cut across the connotative clutter and extract the organizing principle in its pure, conceptual form. But it is also possible, and probably more likely, that he or she will be sidetracked by all the verbiage and lose sight of the taxa being sought. The problem reduces to the fact that it is very difficult, if not impossible, to write comprehensive guidelines for taxonomization in the absence of an actual set of taxa. However, when faced with a particular set of taxa known to share some common feature or attribute, it may be possible to deduce that attribute and express it in meaningfully descriptive words. Then, that particular expression can be of considerable help in a future taxonomization task applied to a system with similar attributes of performance.

To summarize, the guidelines presently incorporated in the STM are better suited to some systems than to others. If the applicability of the STM is to be improved, alternate expressions of those guidelines must be developed and included in the model so that the taxonomization process becomes steadily easier for more and more kinds of systems. This can perhaps best be done inductively, i.e., each time the model is applied, the taxonomic sets that result can be studied as specific examples from which concrete expressions of organizing principles can be derived. Ultimately, entirely different versions of the STM might be developed, each designed for some particular subset of the universe of human-machine systems. Each version will be based on precisely the same concepts. But how those concepts are expressed will be tailored to the peculiarities of its own class of systems.

This last step in the STM utilization procedures thus might have been titled, "Now look at what you've done and use it to improve the STM." It is, in fact, a plea to allow the STM to continue to grow in usefulness by adapting past successes to future applications. A sharing of such successes among all applications analysts would be of considerable future benefit to all.

IV. INITIAL ANALYTIC PROCESS MODEL FOR SYSTEMS MEASUREMENT

The preceding sections described the activities associated with revising, applying, and extending the STM. Those activities accounted for the great majority of the effort expended during the past year. However, none of those activities were pursued as ends in and of themselves. The STM was not revised and extended as a final end product, but merely as the first stage in an overall conceptual model of human-machine system measurement. A preliminary conception of the structure of that overall model (Figure 2 above) had been prepared at the outset of the research to guide the STM's further development along the proper path. That development, in turn, led to a fuller understanding of the total measurement process, and to important revision/clarification of the overall model's structure. Key issues to be addressed in the continuing research also were clarified. These findings are summarized in this section.

A. Groups of Stages in the Overall Measurement Process: The Framework for Further Research.

Figure 23 depicts the four groups of stages in the overall analytic process model (APM) for human-machine system measurement. Each group is discussed below.

GROUP 1: ESTABLISHING THE CONTEXT OF THE MEASUREMENT APPLICATION

This could also be termed the group of "STM Stages", or the "Stages of Taxonomization". The purpose of the process stages included herein is to treat the system-and-mission(s) being studied as the source of variables for the study. The idea is to examine the system's own definition, the definition of its relevant missions, the performance requirements to be achieved, the environment within which the system is to perform, and the constraints governing that performance in such a way that all key variables relating to the effective performance of that system in those missions will emerge. Taxonomization is the method or vehicle for that examination. Performance-relevant variables are identified by isolating the types (classes, populations, etc.) of system to which this particular system belongs by virtue of its potentialities, processes, products, environment, and constraints. The STM is GROUP 1 of the overall CPM. The taxa that are identified through application of the STM provide important input to the determination of what is to be measured and how it is to be measured.

GROUP 2: IDENTIFYING THE FOCUS OF THE MEASUREMENT APPLICATION

The purposes of the process stages included in this group are to select specifically which variables are to be addressed in the measurement application, and to choose the measures to be used to address them. The first stage in this group, viz., selection of practical, measurable attributes, represents the extraction of organized sets of variables from the identified system populations.

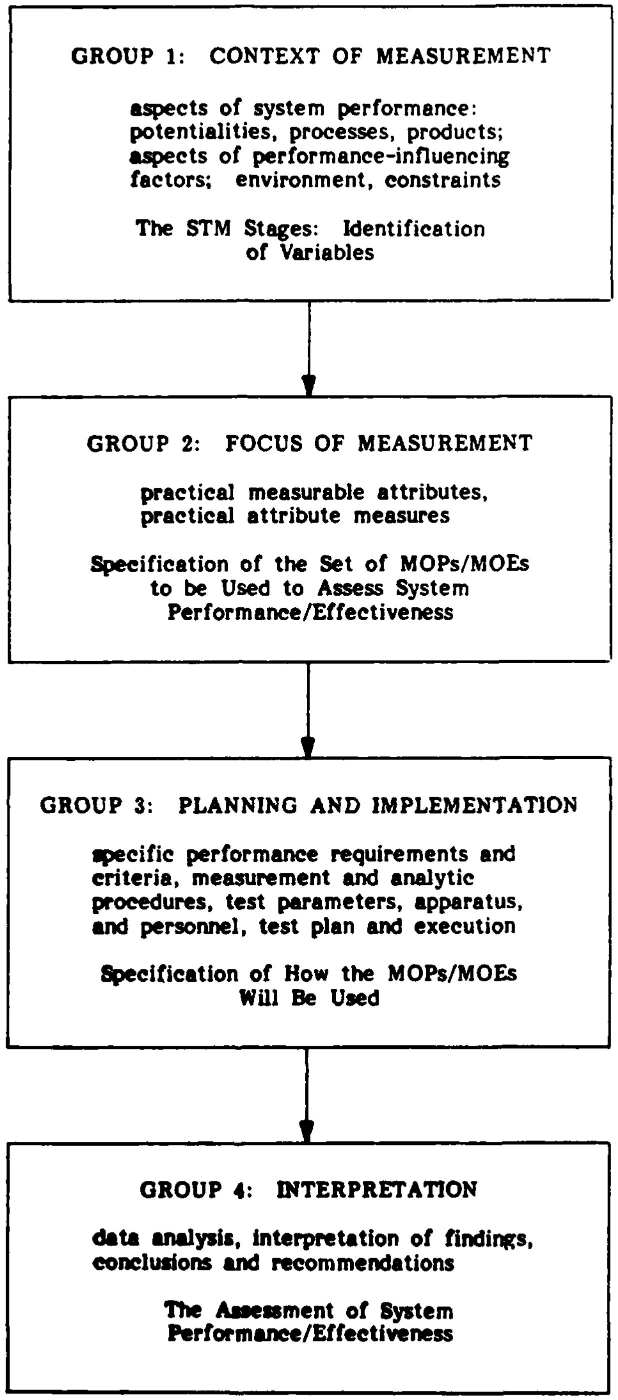


Figure 23. Groups of Stages in the Overall Measurement Process

Each set of variables corresponds to some element or aspect of the particular system's performance in some particular mission. To clarify exactly what this stage entails, the trial application of the STM to one subsystem of the Infantry Fighting Vehicle, namely, the Carrier Team Unit, produced hundreds of distinct taxa. In order to assess a particular aspect of the Carrier Team Unit's work, viz., its performance of "Surveillance," it was necessary first to determine exactly which of those taxa were organized around variables of interest to surveillance. It was found that approximately 75 different taxa applied to surveillance. If the study's purpose had required assessment of some other aspect of the Carrier Team Unit's work (such as "Transportation," "Protection," "Communication," or whatever), some other set of taxa relevant to that aspect of performance would have been identified. That other set possibly would have had some taxa in common with the "Surveillance" set, but certainly would not have been identical to it.

Identification of which taxa (and their underlying variables) are relevant to the particular performance aspects to be assessed is precisely what is required for the selection of practical, measurable attributes. The next stage is to choose measures for each of those taxa. The set of measures is the actual focus of the measurement process. It is usually appropriate and necessary to select several measures for each attribute being studied, because rarely does one measure by itself disclose everything of interest concerning that attribute. For example, in constructing a set of MOPs/MOEs for assessing the Carrier Team Unit's performance of "Surveillance," it was determined that one important attribute to be studied should be the Unit's success in identifying "Enemy Locations." All of the following were proposed as worthwhile measures of that one attribute:

- The kinds of enemy locations that were correctly identified.
- The kinds of enemy locations that were not identified.
- The kinds of enemy locations that were mis-identified.
- The numbers of enemy locations identified (of each kind).
- The numbers of enemy locations not identified (of each kind).
- The numbers of enemy locations mis-identified (of each kind).

The final product of GROUP 2 of the measurement process is the set of MOPs/MOEs, organized around all attributes (taxa) relating to the aspects of system performance/effectiveness to be assessed in the research application at hand.

GROUP 3: PLANNING AND IMPLEMENTING THE DETAILS OF THE MEASUREMENT APPLICATION

The purposes of the stages included in this group are to restate the research issues in terms relevant to the measures, to specify exactly how the measures are to be applied, and finally to apply the measures in accordance with those specifications. The importance of this group notwithstanding, it probably requires less research and development than do the preceding two groups. That is to say, the process of planning and conducting tests, collecting data, controlling parameters, applying statistical procedures, etc. has become a rather exact science (at least, in comparison to the other stages). What remains an art (with much room for improvement) is the process of identifying the pertinent variables and of selecting the appropriate measures. However, one key area for improvement in this group concerns the specification of measurement procedures. If the outcome of the measurement is to be of maximum utility and validity, the measurement procedures must adequately reflect the real-world context in which that system is supposed to work. In particular, those procedures must be specified in accordance with the environment and constraints taxa derived in GROUP 1.

GROUP 4: INTERPRETING THE RESULTS

The purpose of the stages constituting the final group is to formulate answers to the research questions that motivated the assessment of the particular system's performance/effectiveness. Among other issues, this group must somehow permit the information gleaned from the diverse measures to be compiled into some overall rating of the particular system's work. This should be the type of rating that would, for example, allow two competing systems (or system designs) to be compared unambiguously. The process of compiling the information from the measures also should proceed in a fashion that allows specific desirable improvements in the system to be identified.

This four-group sequence corresponds generally to the original conceptualization of the overall measurement process originally depicted in Figure 2. But, some notable changes have occurred in the concepts included within each group. The most extensive of these obviously took place in GROUP 1, which now focuses on a much clearer model of the components or aspects of system performance. However, GROUP 2 also has undergone appreciable revision, in that the relationship of practical measurable attributes to measurement purposes, elements of performance, and system taxonomies now is much more explicitly defined. In addition, the fashion in which MOE/MOP hierarchies associate with elements of performance has been clarified somewhat, at least by example. GROUP 3, too, has been modified, in that it has been established that a direct link exists between procedural specifications and system taxonomies.

These modifications are depicted in Figure 24, the revised conceptual outline of the overall measurement process.

B. Measurement Process Issues to be Addressed in the Continuing Research

It remains now to determine whether a valid and workable overall APM can be constructed around the framework depicted in Figure 24. In order to do so, the authors suggest that the following issues or questions need to be resolved in the near future.

1. Is It Possible and Practical to Facilitate Substantially the System Taxonomization Process?

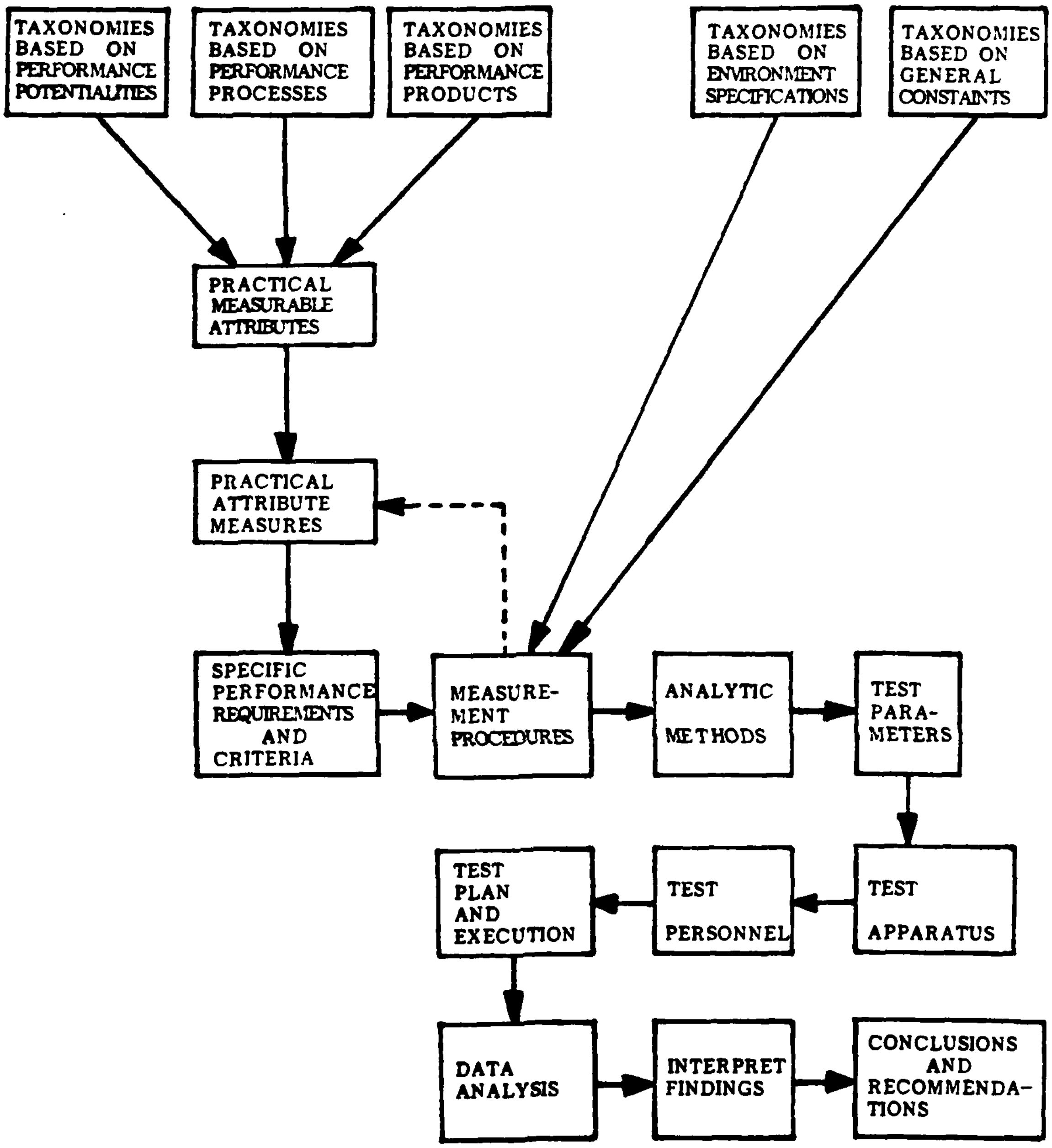


Figure 24. Revised Conceptual Outline of the Measurement Process

In its only major application to date (to the Infantry Fighting Vehicle), the STM initially was very laborious to use. As progress was made in that application, the taxonomization procedures were improved substantially in both specificity and utility. However, further improvements can and should be made. Identification of relevant system taxonomies based on performance potentialities, processes, and products, and on the applicable environment and constraints is the key input to the specification of measures sets and measurement procedures. Anything that will streamline the taxonomization process thus will enhance the utility of the overall APM.

Two related issues, in particular, need to be explored to improve STM specificity and utility. First, is it possible to list representative taxa for each cell of the STM that would be compatible with most of the human-machine systems of potential interest (e.g., military weapons systems)? Second, what is the potential for computer-aiding of the STM utilization procedures? There is no doubt that the total number of populations that exist among the universe of human-machine systems is enormous. However, if one's principal interest is centered on a particular sub-universe of systems, it may be possible to identify a finite, manageable set of populations whose members span the range of variables pertinent to performance/effectiveness measurement of (at least) most of the systems belonging to that sub-universe. In particular, it may be possible to organize that finite, manageable set into subsets corresponding to the cells formed by interaction of the first two dimensions of the STM (i.e., System Descriptive Levels interacting with Measurement Contextual Aspects). This would produce fifteen lexica of system taxa, with each lexicon corresponding to the interaction of one of the three Descriptive Levels with one of the five Contextual Aspects. The existence of these lexica presumably would greatly facilitate the application of the STM to any particular human-machine system belonging to the sub-universe of interest: to identify the total set of taxa for that system, one would search through each lexicon in turn, "pulling out" the populations to which the system belonged. Occasionally, one possibly would discover that the system also belonged to a population not contained in the lexicon. That population could be added to the lexicon to improve its applicability to other systems in the future. The fifteen lexica thus would "grow adaptively," incorporating more of the taxa associated with more of the systems of their sub-universe.

The compilation and use of such lexica should be greatly facilitated by automated data processing. In its trial application to just one subsystem of a (not very complex) military weapons system, the STM produced more than 200 taxa. The "finite, manageable set" of taxa for the class of all such weapons systems easily could have several thousand or even tens of thousands of entries. Manual searching and extracting from such voluminous lexica would be very laborious and error-prone. But if the lexica were maintained in an interactive computer system, it might be possible to reduce the labor involved significantly. Supporting software could be written so that, given certain descriptive features of the system of interest as input, the automated routine might take a "first cut" at selecting at least the Objectives Level taxa (corresponding to the "what" of system performance). Of course, the human analyst could always amend those "first cut" choices by deleting or adding taxa, but at least his or her search time should be shortened substantially. Perhaps more importantly, the computer-based implementation could include a permanent memory of all of its past taxonomization applications. This could allow keeping track, for example, of the frequency with which each population in each lexicon has been selected and of the groupings of populations that have occurred in past applications. The sequence in which populations are presented to the human analyst for his or her consideration could be continually refined based upon the observed frequencies and groupings of previous selections. Given enough previous applications, the software could become progressively "smarter," and become capable of making steadily more accurate "first cut" selections of taxa based on what it has "learned" in the past. It almost certainly will never be possible to dispense entirely with the human analyst in the final selection of taxa, but it should be possible to eliminate much of the work that presently is required. Furthermore, it should be relatively easy to design the memory to permit new entries to be made to the lexica, and even to delete old, never-chosen entries as time goes on.

2. Can Explicit Procedures Be Developed for Identifying Which Taxa are Relevant to Any Given Element or Aspect of System Performance?

As a result of the first year's research, explicit, workable procedures were developed for identifying relevant system populations, on three different Levels of System Description, associated with the system's potentialities, processes, and products of performance. From the viewpoint of the overall APM, the sole purpose for identifying those taxa is to provide sets of practical, measurable attributes, on the basis of which particular elements of the system's performance/effectiveness can be assessed. But the question remains: given some performance element of interest, and given the array of performance-based taxa, how does one determine—systematically and analytically—which taxa represent attributes relevant to that performance element? What are the procedures for determining the hierarchy of taxa associated with any given element of a system's performance?

In the trial application of the STM to the Infantry Fighting Vehicle, the preceding questions were not directly addressed. However, as a "test" of the validity of the taxa identified, an attempt was made to construct a set of MOPs/MOEs for one element of that system's performance, namely, its performance of "Surveillance." The first step was to isolate the potentiality, process, and product taxa that bear on "Surveillance." Of 221 taxa associated with the three perspectives of performance, 42 were identified as having relevance to measurement of "Surveillance." That is, those 42 taxa became the practical, measurable attributes that would be used for that particular assessment of performance/effectiveness.

But how were those 42 taxa identified? Very simply, they were identified because they "seemed" to the analyst, "intuitively," to have something to do with surveillance. The remaining 179 taxa "intuitively seemed" not to have anything appreciable to do with surveillance, and so were not chosen as attributes for the measurement process.

The identification of measurable attributes based on intuitive feelings was reasonable for the limited purpose of testing the output of the STM trial application, but something much more precise and systematic is needed for the future. Without some means of insuring that all of the proper taxa, and only the proper taxa are chosen, all of the work expended thus far in developing a systematic taxonomization process will not have achieved its potential. If the intuitive selection either fails to include some relevant attributes, or includes some that are not relevant to the performance element in question, the set of measures ultimately constructed will not be completely valid. And as a result, a distorted assessment of performance/effectiveness will emerge. Ultimately, guidelines should be developed for identifying the subset of taxa applicable to any particular system measurement need.

3. Can Explicit Procedures Be Developed for Selecting Measures for Each Identified Attribute of Performance?

This is the logical extension of the previous issue. Once explicit procedures/guidelines for identifying the measurable attributes are in place, it will be necessary to develop similar procedures for determining exactly how those attributes should be measured. In the present state-of-art of human-machine system measurement, the selection of measures is another of those crucially important steps for which no widely used systematic process exists. Instead, measures are chosen intuitively, in hit-or-miss fashion. As a result, the analyst can never be sure that he or she has chosen the most appropriate measures to examine any particular attribute. For example, 141 measures were identified for the 42 "surveillance"-related attributes associated with the Infantry Fighting Vehicle. All appear intuitively to be valid, worthwhile measures. But presently there is no means of determining whether these are the best available measures for those attributes, nor is there any way of proving, a priori, that all of these measures are in fact valid and worthwhile. Given the same array of attributes, another analyst might choose a quite different hierarchy of measures. Who is to say which hierarchy would be superior?

4. Is It Possible and Practical to Develop Methods of Specifying Performance Requirements and Measurement Procedures?

Assuming the preceding research issues are resolved, explicit procedures will have been developed for GROUPS 1 and 2 of the overall APM. This issue concerns the first extension of the model into GROUP 3. The focus of attention here is on the commencement of formal planning for testing the system's performance/effectiveness. Specification of performance requirements must be accomplished in relation to each chosen measure of performance/effectiveness. That is, the elements of system performance of interest to the measurement application at hand must be expressed in terms of the measures. For example, suppose the measurement application were focused on the Infantry Fighting Vehicle and on its performance of surveillance. It would be necessary to establish specific requirements in terms of all 141 measures of that performance element, i.e., requirements relating to the kinds of sectors to be assigned to the system, the numbers and types of enemy locations to which the system is to be exposed, the maximum tolerable false alarm and missed target rates, the kinds and numbers of targets and target signatures to be deployed, etc. All of these specifications are important inputs to the test scenarios that will provide the measurement context. The other major input to the scenarios and the overall test plan is the set of measurement procedures, i.e., the specification of precisely how, when, and where the measures will be taken. These derive, in part, from the specific requirements and procedures, and in part from the taxa associated with performance-influencing factors (environment and constraints). Choosing the correct measurement procedures is every bit as important as choosing the appropriate measures themselves. A valid measure will be of no value, and might even confound the assessment of system performance/effectiveness, if it is not applied at the right times and places, e.g., when/where the necessary data are available. If applied carelessly, the measurement process might actually interfere with the performance being studied, or create other unanticipated and undesirable effects that contaminate the data. Clearly then, it is not sufficient that the model include explicit procedures for choosing the right measures. It also needs to possess explicit procedures for determining how to use those measures.

5. Assuming That The Previous Questions Can Be Answered Affirmatively, What Specific Benefits Can Be Achieved?

If the preceding four issues can be resolved, a model will have been constructed of the measures selection/measurement procedures specification portions of the overall measurement process. That is, approximately the first half of the overall APM will be available. It then will be appropriate to assess the utility of that partial model for accomplishing certain key applications. Chief among these applications will be the following:

- Utility of the model for differentiating between MOEs and MOPs and identifying the MOE/MOP functional relationships and for breaking out measures hierarchies for subsystems.
- Utility of the model for identifying the human contribution to each system MOE/MOP, and in turn for identifying appropriate measures of human performance.
- Utility of the model for providing input to system definition and specification (as well as to system evaluation).

The concluding section of this report presents specific plans for a research effort designed to address the issues just discussed and others derived from the earlier subtasks in this research project.

V. RESEARCH REQUIREMENTS AND PLANS

The need to address certain major research issues was determined during the two major endeavors of this study, viz., the state-of-art review of system measurement and the STM revision and application to the IFV. Within each of the major issues, a number of specific implications for research planning may be found. These implications are discussed below, in subsection A, with reference to their origins in the state-of-art review and the STM revision/application. A recommended research plan based on these implications is outlined in subsection B.

A. Implications for Research

In the state-of-art review of measurement literature for this project (Edwards et al.. 1981),* it became apparent that measurement models need to be further developed, supported with appropriate human performance data, refined through more consistent and comprehensive applications, and validated by independent corroborations of some kind. Furthermore, the general sense of impracticality and the need for simplifying assumptions in some cases strongly suggest a requirement for improving the "efficiency" of measurement models by reducing the magnitude of effort required, while remaining true to the real world of the system under assessment. This latter need for procedure magnitude reduction could be accomplished in a stepwise fashion by an overall direct effort, supported by individual limited efforts for the clarification and simplification of specific concepts and the modification of analytic approaches. One of those approaches, for example, could be the introduction of computer-aided procedures employing carefully developed taxonomies and checklists.

The literature review cited several authors who noted severe limitations on system measurement (Blanchard et al., 1969; Clovis et al., 1975; Kelley, 1968; Levy, 1968; Meister, 1968; Pew et al., 1977; Rigby, 1967; and Ultrasystems, Inc., 1972). One concern, expressed by Blanchard et al. (1969), was the lack of valid human performance data, a problem which can seriously limit the utility of an evaluation model. Subjectively derived performance data continue to be given prime emphasis, and it was felt that this is not likely to change soon. Clovis et al. (1975) suggested that in dealing with the limitations of their study, a cross-validation effort be conducted to test the efficiency of the regression equations used in calculating the index of performance. Also, it was recommended that situational exercises be used to validate and to provide practical application guidelines. Kelley (1968) made the point that human performance is not linear and may be poorly represented by linear control-theory models except for fairly simple or restricted tasks. Also, human control is exercised not on the basis of present error, but rather on the basis of future (anticipated) error.

A need for validation of man-machine models was noted by Levy (1968). It was suggested that a research design for developing and validating applied models be undertaken. This design would call for the collection of performance

*For convenience, all reports cited here are listed at the end of this section.

data and input data in field situations with the input data recorded for use in laboratory studies aimed at model development. The models, in turn, would be validated by comparing their outputs with the pre-collected field performance data. Meister (1968) discussed the human reliability model primarily as a means of illustrating certain characteristics of behavioral models in general and certain characteristics of model makers themselves. In the author's view, a model is effective to the extent that it helps to either gather data and/or to explain those data. He stated that any behavioral model which is not concerned with real-world data (as opposed to laboratory data) is not useful. However, he observed that behavioral models characteristically employ laboratory data and have ignored or have been unable to handle natural event data. The author asserted that the human reliability model's assumptions derive from the unsystematic manner in which the model's input data were secured and that, at least in part, these assumptions demonstrably are not in accord with empirical reality. Pew et al. (1977) noted that, for the most part, human information processing models deal with the average performance of well motivated, high-practiced individuals under relatively ideal conditions. There are many hypotheses but few data and virtually no models in the information processing literature on how human performance capacities change under stress, reduced motivation, or before practice has stabilized performance. Rigby (1967) asserted that the development of an accurate data base of human error rates is impeded by several factors--accidents and mission failures resulting from human error are not reported as regularly or as accurately as equipment failures, and that there is a lack of standardization in terminology, manner of development and level of reporting.

Finally, Ultrasystems, Inc. (1972) presented 12 areas of limitations on system measurement. First of all, it was noted that the criteria for success are seldom stated explicitly and that there exists more than one way of defining a mission as well as more than one way of quantifying how well the criteria for success are met. It was noted that the rationale for MOE selection is not always presented and, in general, the MOEs used are those that are readily obtained via model development. Very seldom, when more than one MOE is identified, is a ranking of importance given or a combined measure developed and used. Expected value type MOEs are most prevalent in force level studies, whereas probability type MOEs are most often found in subsystem level studies. With regard to independent variables, it was felt that over twice as many occur in the friendly force category than in the threat and target categories combined. In addition, as the study level increases from subsystem to system to force level, the percentage of independent variables in the friendly force category decreases and the friendly force interaction with threat or target category increases. It was noted that there are cases in which the variables selected for model formulation are not readily (if at all) measurable in the real world. Physical environment aspects appear to be generally ignored or casually treated in effectiveness studies and, finally, it is not easy to compare similar effectiveness studies.

In summary, it appeared that limitations of major concern to those developing models are the lack of valid human performance data (resulting in part from the absence of information on performance under "real-world" conditions), lack of standardization in development and reporting of data, and the need to validate man-machine models with field performance. In addition, limitations in system measurement were reported to exist in the areas of defining a mission and quantifying its success, lack of rationale in MOE selection and the selection of variables which are measurable in the real world. There was some discussion in the documents reviewed of priorities for measurement improvement. In most cases, recommendations were limited to the system of specific interest to the author and generally were directed toward verification of the research just completed. Several authors, however, made recommendations for future research which would have broader application to system measurement improvement.

Regarding the absence of a body of quantitative evidence about the performance effectiveness of personnel in present systems, it was suggested that, as a first step, a data bank on personnel performance be developed that would select samples of personnel performance which could be generalized to entire classes of populations. One study recommended that large quantities of data from multiple trials be methodically built into a data base for each variable, team member and subtask of a standard test. In addition, it recommended that objective field monitoring techniques, such as video recordings, should be utilized to provide standard structured coverage by separate variables and subtasks.

Some studies recommended research on combining subtasks or models to assess performance in more complex tasks and aggregate systems. Yet another addressed the problem of estimating conditional probabilities of dependent task steps. It noted that two major problems must be solved in this effort: 1) the identification of factors responsible for dependent relationships among task steps, and 2) determination of the effects of dependent relationships. Others (Finley et al., 1975; 1976) actually began the improvement process by developing basic STM principles and concepts that would lead to the present study.

In addition to the literature review, the trial application of the STM to the IFV produced a wealth of insights and implications concerning system measurement. It was discovered that the organizing principle for any of the STM's "cells" could be described as an open-ended statement, augmented by a series of specific analytic questions. All of these analytic questions were derived in the context of the IFV, but they appeared suitable for commencing the taxonomization process for most human-machine systems. As other applications of this concept are completed, additional useful analytic questions undoubtedly will emerge. This first major application of the STM was exceedingly laborious and time-consuming. But, substantial progress was made toward developing specific taxonomization procedures and guidelines, and future applications can be expected to proceed much more efficiently, and lead to steadily increased utility of the STM.

In summary, the work of the Dunlap project staff and the published reports of other researchers have served to identify a number of major limitations in the state of the art of measurement models. Clearly the steps and concepts of the measurement process must be defined more specifically, the model application guidelines must be better described, the categories of populations and measures must be structured more specifically into appropriate taxonomies, the level of effort required for applying the model must be reduced to more practical levels, and a human performance data base is needed to help later assessment of the potential, the process and the performance of any system. The positive results of the STM application to the IFV indicate that one of the most promising approaches to model development is that of sample applications to real systems. Therefore, a series of applications must be carried out, not only for the purpose of system performance measurement and evaluation but for other potential purposes the model might serve, such as the assessment of personnel performance in existing systems, or the development of design specifications and training programs in planned systems. In the process of this needed development effort, there will also be an opportunity to address specific issues, such as the relationship between MOEs and MOPs, the role of operators in the total measurement process, the problems associated with eventually placing the measurement model on an interactive computer system for machine-aided application, and methods for carrying out some of the above activities (such as for collecting a consistent base of human performance data).

It is envisioned that much time, effort, and money can be saved, irrelevant measurements can be avoided, and meaningfulness can be enhanced by making the kinds of improvements noted above. Ultimately, these improvements could make the difference between an oversized, difficult-to-use measurement and evaluation procedure with limited acceptance and few users and a clearly established, easy-to use procedure with wide acceptance and many users.

B. Research Items: Scope, Potential Significance, and Resource Implications

The kinds of measurement model issues and research implications that were identified above appear to be assignable to three convenient categories of study: development, application and special or limited study items. Figure 25 lists those items within the three categories.

In order to determine the scope, potential significance and resource implications of each research item, five Dunlap professional staff members* who were most involved in this project met to review all items and to reach a consensus on their ratings. After a brief description of a research item, each project staff member made an independent assessment of the underlying limitation(s) necessitating the additional research (basic theory, application history, essential technology), the potential results of the research (remove or reduce the deficiency), the priority for completion (high, medium, low), the effort required (professional person-months), the duration of the required effort (months), a start date (year) and a preliminary cost estimate (dollars). After these independent assessments were made, each item was discussed and all raters were then permitted to change their assessments. When all were satisfied with their individual ratings, a tally was made which formed the basis for the final consensus discussion. The conclusions of the project staff regarding each future research item are in the following paragraphs.

Item 1. Further Development of the Overall Analytic Process Model for Manned System Measurement

The purpose of this research item is to advance model development further toward the ultimate goal of providing a practical and useful end product. The research task ultimately should address all stages of the model in order to extend its conceptualization and development in each of its aspects. The research method should include model application and analysis with several systems to verify or modify its component parts, its adequacy, and its practicality. The effort should also produce revised or newly recommended procedures and guidelines for using the model. This is considered a high priority item because of its intrinsically broad and basic nature.

*The five staff members were: Dr. Richard F. Bloom (Project Director); Mr. John F. Oates, Jr.; Mr. John W. Hamilton; Ms. Joan Edwards; and Mr. Paul Brainin.

- **Development Items**

  1. Further Development of the Overall Analytic Process Model for Manned System Measurement
  2. Further Development of Procedures for Deriving "Practical Measurable Attributes" from the "Contextual Components" of the Overall Model
  3. Further Development of Taxonomies within the System Taxonomy Model
  4. Further Development of Procedures and Guidelines for Carrying Out the Application of the Analytic Process Model
  5. Procedure Magnitude Reduction
  6. Development of a Human Performance Data Base

- **Applications Items**

  7. Extension of the First Application of the Measurement Model to the IFV
  8. Second Application of the Analytic Process Model to an Army System
  9. Application of the Analytic Process Model to Personnel Performance Assessment
  10. Application of the Analytic Process Model to Developing System Design Specifications

- **Limited Study Items**

  11. Relationship Clarification for MOEs and MOPs
  12. Clarification of Operator Roles in System Measurement and Evaluation
  13. Implications of Placing All or Part of the Analytic Process Model on an Interactive Computer System
  14. Identification of Requirements for Collecting Human Performance Data
  15. Development of Standards for the Reporting of Human Performance Data

Figure 25. Future Research Items

Item 2. Further Development of Procedures for Deriving "Practical Measurable Attributes" from the "Contextual Components" of the Overall Model

The purpose of this research item is to help facilitate and standardize utilization of the overall measurement process model. The research should address the specific transition point within the model which links the system performance and performance-influencing factors identified as the output of taxonomization with the next step (at the beginning of the focal group) called "Identification of Practical Measurable Attributes." Guidelines for deriving those measurable attributes and sets of specific candidate attributes should be generated in this task. The research method employed should apply and analyze the model with several systems to help identify the best ways of deriving measurable attributes. This is considered a high priority item because it lies in the critical sequence of steps in applying the overall model. Failure to improve upon this transition step could impede use of the model and result in inappropriate or ineffective system measurement.

Item 3. Further Development of Taxonomies within the STM

The purpose of this research item is to extend and clarify the taxonomies within the cells of the STM. The research also should further develop the structure and compile detailed classifications for guiding users of the overall APM. The methods used should include: the review and adaptation of taxonomies from prior research; the extension and development of additional taxonomies; the employment of codification strategies identified in prior research; and the structuring of the final recommended taxonomies to be compatible with use on interactive computer. This is also considered a high priority item because it impacts directly on the ease of using the STM and the overall APM. It will insure a greater degree of standardization, or at least compatibility between the analyses of different systems and different researchers.

Item 4. Further Development of Procedures and Guidelines for Carrying Out the Application of the APM

The purpose of this research item is to refine and extend the rules for performing the steps of the APM. It is a more specific and in-depth development of guidelines than is found in Item 1, and does not involve the further development of the model itself (as Item 1 does). The research should include a review of all prior applications of the model and the guidelines employed, the identification of areas needing further clarification and the providing of such clarification by refinement and extension of the guidelines. This is considered a high priority item because of its direct impact on the effective application of the model, and its potential for helping to maximize standardization and precision in the model's use.

Item 5. Procedure Magnitude Reduction

This most important research item is directed at reducing the amount of effort and resources required for a satisfactory application of the measurement model, so as to make the process practical for general use. It was found in the applications conducted to date that the process could easily become extremely time-consuming and exhaustive. It is apparent that ways of reducing the number and complexities of analyses can be found, without significantly undermining confidence in the results. The procedures used in this research task should involve the application and analysis of the process model with several systems to insure the necessity and efficiency of each step, plus minimization of the procedures by eliminating, combining, replacing, prioritizing, and other methods. The task should produce an end product consisting of recommended guidelines for procedures of reduced complexity and other guidelines for generating further complexity reduction in specific applications. This task is considered to be the highest in priority of all those recommended here because it bears such a direct impact on whether use of the model can even be tried in the context of projects with fixed and limited resources of time, money and manpower. If found to be too time-consuming or costly, the model may be abandoned regardless of how effective it can be. The present research task would keep the model application effort compatible with total system development effort.

Item 6. Development of a Human Performance Data Base

The purpose of this task is to assemble a data base of human performance information in compliance with previously determined requirements, for use in the evaluation of manned systems. Of primary use in determining system effectiveness by providing criteria for assessing human performance in specific cases, this task would also be potentially useful to all human factors, operations, and systems analysts, whether they use this project's measurement model or some other one. The task should be carried out by reviewing the findings provided in current human performance literature and assembling relevant existing data into a preliminary base of human performance information. It should also define the need for further research to obtain missing data or to replace inadequate data. Despite its potentially widespread applicability, and its implications for long lead times if new data need to be developed, this task is considered to be of medium priority because its direct impact on model development is less than critical.

Item 7. Extension of the First Application of the Measurement Model to the IFV

Derived directly from research conducted under the present contract, this task recognizes the complexity and exhaustive effort represented by a vigorous application of the model. Clearly, project resources did not allow more than a limited trial application of the model to the IFV. The recommended research item is intended to develop further the techniques, concepts, and guidelines for practical application of the measurement model, by continuing the same application example with the IFV. Continuation of this kind will allow for work to be conducted on more components of the system hierarchy (subsystems, collateral systems, and suprasystems) and to a greater depth at the three system description levels (Objectives, Functional Purposes and Characteristics). This task should, therefore, continue the prior application of the STM to the IFV, enlarge upon the limited sample of steps and depth previously employed, and enlarge upon the guidelines developed for application. This task, too, is seen as having a high priority because it directly affects, through actual application, the overall development of a useful measurement model.

Item 8. Second Application of the APM to an Army System

It is considered essential that there also be applications to some other systems than the IFV, and/or to the IFV with another measurement purpose in order to facilitate the generalizability of the model for use in analyzing different systems. General applicability to various systems would be manifested by practical techniques, concepts and guidelines for utilizing the measurement model. The research effort should consist of selecting a manned system and measurement purpose other than the one used in the prior IFV case, and then applying and further refining the model. This task is considered to be of high priority, since it will clearly improve the applicability of the model. Nevertheless, meaningful model development could still proceed even in the absence of this task.

Item 9. Application of the APM to Personnel Performance Assessment

Work with the STM has suggested that the overall model's products would be useful in areas other than that motivating the current research. One of the potential areas of model application is in the assessment of personnel performance in operating systems. This task would attempt to determine the applicability of the APM in assessing personnel performance, in both quantitative and qualitative terms. The research should identify a suitable personnel activity and measurement purpose and then apply the model so as to assess its ability to produce the personnel assessment measures useful in determining performance. The task output should also include recommended application guidelines for this kind of application. As a secondary, though valuable application of the model, not essential to the primary development effort, this task is considered to be of medium priority.

Item 10. Application of the APM to Developing System Design Specifications

Another application area is in the development of design specifications for planned systems. The goal of this task is to determine the feasibility of using the APM to assist in developing system design specifications and other routine documentation associated with the system design phase. In conducting this task, the researchers should: select one or more appropriate systems currently in the design phase; apply the model to help specify operating requirements; use model-generated information to aid in completing design phase documentation, and recommend guidelines for this application. As in Item 9, this potentially valuable, secondary application study is considered to be of medium priority.

Item 11. Relationship Clarification for MOEs and MOPs

In the attempt to clarify further certain concepts and terms used in applications of the measurement model, the specific need for precision of meaning interrelationships and consequent focus of effort was recognized in regard to measures of effectiveness (MOEs) and measures of performance (MOPs). Traditionally, effectiveness measures are criterion-referenced indicators while performance measures are simply normative indicators. Other usage suggests that effectiveness measures directly address the primary mission product or goal (e.g., time for a runner to reach the finish line), while performance measures address related process factors which may or may not determine ultimate effectiveness (e.g., the runner's heart rate). Furthermore, the MOE at the subsystem level could be an MOP at the higher system level. These and other issues should be examined by defining MOEs and MOPs for one or more selected systems and their hierarchical counterparts. The study should note how MOEs at one level can be MOPs at another level. Finally, a summary report should be prepared which describes the essential characteristics of MOEs and MOPs. Although this clarification of terms is important for the precise application of the model, relative to the other research items noted here it is considered to be of lesser priority.

Item 12. Clarification of Operator Roles in System Measurement and Evaluation

Another issue that emerged as requiring specific clarification, so as to facilitate effective model use by those not well-versed in human factors engineering, is the one identifying the many (sometimes subtle) roles of operators and their output quality in relation to system effectiveness. Researchers should apply the appropriate techniques of Human Factors Engineering to define the roles and influence of operators in the various system attributes selected for measurement in order to carry out this task. Because this kind of human factors sensitivity is essential, and some researchers using the model in the near future may require assistance in developing such an orientation, this task is considered to be of medium priority.

Item 13. Implications of Placing All or Part of the APM on an Interactive Computer System

It is foreseen, even at this relatively early date, that a reduction in the magnitude of effort required and greater ease in applying the model can be greatly enhanced if an interactive computer system is employed. Such a system could reduce the user's creative effort by presenting a sequence of general-to-specific questions or checklists and by using branching routines that insure thoroughness, proper use of concepts, and avoidance of departures from the guidelines. This research task is intended to determine the feasibility and resource implications of incorporating the APM (or at least the STM) onto an interactive computer system for machine-aided applications. In its execution, the task should include the examination and step-by-step documentation of procedures followed in one or more model applications. It should then assess how each step could have been programmed on an interactive computer, especially those steps in the model application which necessitate the analyst's review of taxa. Because this innovation in using the model is probably important only after more basic development is completed, it is considered to be of relatively lesser priority.

Item 14. Identification of Requirements for Collecting Human Performance Data

This task should be completed prior to Item 6 (Development of a Human Performance Data Base), so that the kinds of human performance data to be assembled are identified clearly. This research item should define the recommended task areas, operator characteristics, environments and other conditions for which data on human performance are required. This should be accomplished by reviewing specific data requirements noted in the measurement and evaluation literature, and in this project. That review should be instrumental in helping to determine the requirements for specific data on human performance, operator and operating parameters, and environmental conditions. To the extent possible, the products of this research should indicate the application areas or steps to be aided by the identified data requirements. This task is considered to be of medium priority because, while not critical, it will help to identify gaps or missing information needed for meaningful use of the APM.

Item 15. Development of Standards for the Reporting of Human Performance Data

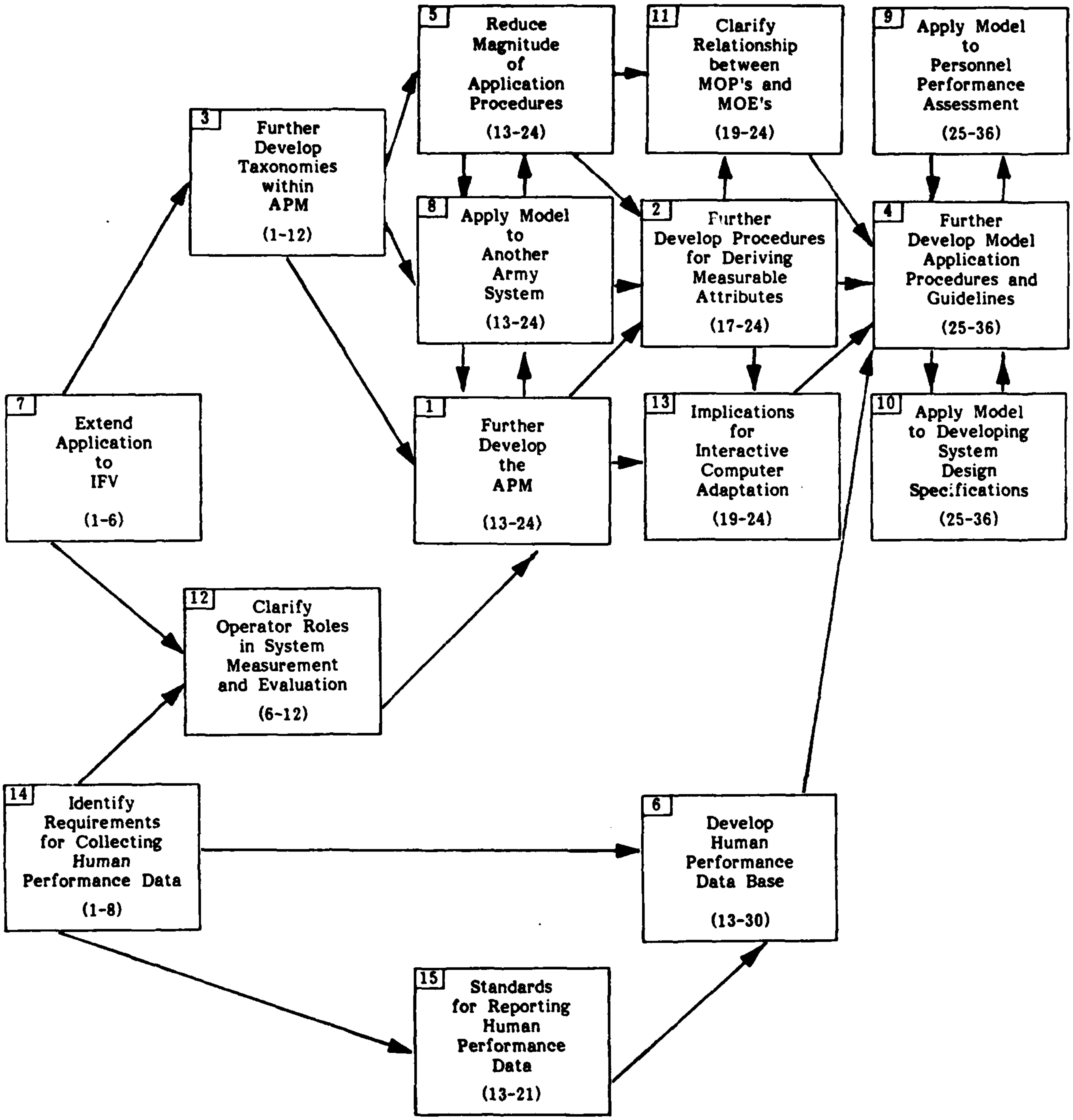
Also related to Research Items 6 and 14, this task is intended to recommend standard conditions and constraints to be used in the reporting of human performance data from field and laboratory research. It should be completed concurrently with or subsequent to Item 14, and before any experimental work on Item 6 is carried out. It should make use of the defined needs from Item 14 to help specify the conditions and constraints necessary for future reporting of human performance data intended for use in system measurement and evaluation models. Its priority is considered to be medium, being less important than determining data requirements (Item 14) and unnecessary if the development of a data base (Item 6) is ruled out entirely.

The 15 research items described in the previous section are summarized in Figure 26. They are also placed in rank order based on the scores received in the project staff assessment described previously. Figure 27 shows a simplified diagram of their interdependencies. The estimated start dates for each item determined the way in which the proposed research plan of Figure 28 was constructed. Three consecutive years of integrated work are indicated for a grand total of 235 professional person-months (19.6 professional person-years). The total cost of $1470K was estimated using a rule-of-thumb of $75K per professional person-year. If the work is divided into three separate year-long efforts, the integrated costs are $345K, $685K and $440K for years 1, 2, and 3, respectively. These "integrated" costs reflect economies expected to result when several tasks are performed concurrently, so these figures are lower than the straight sums of the independent task items in the column for each year.

It should be noted that this recommended plan represents the needs and estimates of the human-machine systems measurement research program as viewed from the perspective of the Dunlap staff only. Unquestionably, any final research plan should also account for factors not known to this staff, for influences and factors emerging after this report is issued, and for other factors known only to staff members of the Army Research Institute.

Rank	Research Item	Est'd Effort (mm)	Est'd Duration (mos)	Est'd Start Date	Est'd Cost ($)
1	5. Procedure Magnitude Reduction	18	12	1982	115 K
2	4. Further Development of Procedures and Guidelines for Carrying Out the Application of the APM	18	12	1983	115 K
3	1. Further Development of the APM for Manned System Measurement	36	12	1982	225 K
	2. Further Development of Procedures for Deriving "Practical Measurable Attributes" from the "Contextual Components" of the Overall Model	12	8	1982	75 K
	7. Extension of the First Application of the Measurement Model to the IFV	12	6	1981	75 K
4	3. Further Development of Taxonomies within the STM	30	12	1981	190 K
	8. Second Application of the Measurement Model to an Army System	18	12	1982	115 K
5	9. Application of the APM to Personnel Performance Assessment	24	12	1983	150 K
6	12. Clarification of Operator Roles in System Measurement and Evaluation	9	6	1981	60 K
7	14. Identification of Requirements for Collecting Human Performance Data	12	8	1981	75 K
	6. Development of a Human Performance Data Base	36	18	1982	225 K
8	10. Application of the APM to Developing System Design Specifications	24	12	1983	150 K
	15. Development of Standards for the Reporting of Human Performance Data	9	9	1982	60 K
9	13. Implications of Placing All or Part of the APM on an Interactive Computer System	6	6	1982	40 K
	11. Relationship Clarification for MOEs and MOPs	6	6	1982	40 K
	Totals	270 mm			$1710 K

Figure 26. Rank-Ordered List of Research Items



Legend: Numbers in parentheses indicate proposed months of performance (i.e., start month - end month) Ref. Figure 28

Figure 27. Inter-Relationships of Research Items

Research Item	Time 1981	Time 1982	Time 1983	Est'd Effort (mm)	Est'd Cost ($)
Development					
1. Further Development of the Overall Analytic Process Model for Manned System Measurement		XXXXXXXXXXXX		36	225 K
2. Further Development of Procedures for Deriving "Practical Measurable Attributes" from the "Contextual Components" of the Overall Model		XXXXXXXX		12	75 K
3. Further Development of Taxonomies within the Systems Taxonomy Model	XXXXXXXXXXXX			30	190 K
4. Further Development of Procedures and Guidelines for Carrying Out the Application of the Analytic Process Model			XXXXXXXXXXXX	18	115 K
5. Procedure Magnitude Reduction		XXXXXXXXXXXX		18	115 K
6. Development of a Human Performance Data Base		XXXXXXXXXXXX	XXXXXX	36	225 K
Application					
7. Extension of the First Application of the Measurement Model to the IFV	XXXXXX			12	75 K
8. Second Application of the APM to an Army System		XXXXXXXXXXXX		18	115 K
9. Application of the APM to Personnel Performance Assessment			XXXXXXXXXXXX	24	150 K
10. Application of the APM to Developing System Design Specifications			XXXXXXXXXXXX	24	150 K
Limited Study					
11. Relationship Clarification for MOEs and MOPs		XXXXXX		6	40 K
12. Clarification of Operator Roles in System Measurement and Evaluation	XXXXXX			9	60 K
13. Implications of Placing All or Part of the APM on an Interactive Computer System		XXXXXX		6	40 K
14. Identification of Requirements for Collecting Human Performance Data	XXXXXXXX			12	75 K
15. Development of Standards for the Reporting of Human Performance Data		XXXXXXXXX		9	60 K
Estimated Level of Effort/Cost mm/$ (Straight Sums)	63/400 K	129/810 K	78/500 K	270 mm	$1710 K
Estimated Level of Effort/Cost mm/$ (Integrated)	55/345 K	110/685 K	70/440 K	235 mm	$1470 K

Figure 28. Proposed Research Plan

C. References for Section V.

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APPENDIX A - CARRIER TEAM TAXONOMIES

Carrier Team Subsystem

1.0 System Definition (Objective Level)

The carrier team must be capable of:

1.1 Providing carrier team surveillance

1.2 Conducting fire of weapons operations

1.3 Providing for squad command and control

1.4 Providing squad transportation

1.5 Providing for squad and platoon communications

1.6 Providing squad protection

Carrier Team Subsystem

1.0 System Definition

1.1 Providing carrier team surveillance (objective level)

1.1.1 Conduct sector surveillance (functional purpose level)

Characteristics Level

The system must have ability to:

1.1.1.1 Visually conduct sector surveillance, ground and air, (TC, Gunner) with unaided optics (direct vision)

1.1.1.2 Visually conduct sector, ground, surveillance with aided optics (image intensification)

1.1.1.3 Visually conduct sector surveillance with IR sensing device (sighting system) during periods of low visibility

Carrier Team Subsystem

1.0 System Definition

1.1 Providing carrier team surveillance (objective level)

1.1.2 Ability to detect targets (functional purpose level)

Characteristics Level

The system must have ability to:

1.1.2.1 Visually detect targets/target signatures, air or ground, unaided vision

1.1.2.2 Visually detect targets/target signatures, air or ground, aided vision

1.1.2.3 Detect target with IR sensor, ground target

Carrier Team Subsystem

1.0 System Definition

1.1 Providing carrier team surveillance (objective level)

1.1.3 Ability to acquire targets (functional purpose level)

Characteristics Level

The system must have ability to:

1.1.3.1 See the target, air or ground visually, unaided

1.1.3.2 See the target, ground visually, with aid of IR sensor

Carrier Team Subsystem

1.0 System Definition

1.1 Providing carrier team surveillance (objective level)

1.1.4 Ability to identify and classify targets (functional purpose level)

Characteristics Level

The system must have ability to:

1.1.4.1 Identify and classify the following type targets visually, aided/unaided:

- Tank
- BMP
- ATGM
- Arty
- Wheeled vehicle
- CP area
- Personnel
- Aircraft
- Bunker
- Etc.

1.1.4.2 Identify and classify the following type targets with IR:

- Tank
- BMP
- ATGM
- Arty
- Wheeled vehicle
- Personnel
- Etc.

Carrier Team Subsystem

1.0 System Definition

1.1 Providing carrier team surveillance (objective level)

1.1.5 Capability to track targets (functional purpose level)

<u>Characteristics Level</u>

System must have ability to:

1.1.5.1 Track a moving target via stabilized platform while own vehicle is moving

1.1.5.2 Track a stationary target via stabilized platform while own vehicle is moving

1.1.5.3 Track a moving target while own vehicle is stationary

Carrier Team Subsystem

1.0 System Definition

1.2 Conducting fire of weapons operations (objective level)

1.2.1 Ability to select weapons (functional purpose level)

Characteristics Level

System must have ability to:

1.2.1.1 Select 25mm gun for medium to long range engagements

1.2.1.2 Select 7.62mm coax MG for medium to short range engagements

1.2.1.3 Select 5.56mm Firing Port Weapons for short range engagements

1.2.1.4 Select TOW for long range anti-armor engagements

Carrier Team Subsystem

1.0 System Definition

1.2 Conduct fire of weapons operations (objective level)

1.2.2 Ability to select ammunition and fire rate for 25mm gun (functional purpose level)

Characteristics Level

System must have abiiility to:

1.2.2.1 Select 25mm AP, single shot, low fire rate, high fire rate

1.2.2.2 Select 25mm HE, single shot, low fire rate, high fire rate

Carrier Team Subsystem

1.0 System Definition

1.2 Conducting fire of weapons operation (objective level)

1.2.3 Capability to determine range to target (functional purpose level)

Characteristics Level

System must have ability to:

1.2.3.1 Provide capability to estimate range utilizing day/night sight (ranging V)

1.2.3.2 Provide capability to fire 25mm high velocity flat trajectory ammunition up to medium-long range

1.2.3.3 Provide capability of producing visual traceable fires (25mm and 7.62mm ammunition)

Carrier Team Subsystem

1.0 System Definition

1.2 Conducting fire of weapons operation (objective level)

1.2.4 Ability to load weapons (functional purpose level)

Characteristics Level

System must have ability to:

1.2.4.1 Load/reload 25mm AP & HE

1.2.4.2 Load/reload 7.62mm Coax MG

1.2.4.3 Load/reload TOW

Carrier Team Subsystem

1.0 System Definition

1.2 Conducting fire of weapons operation (objective level)

1.2.5 Ability to aim weapons (functional purpose level)

Characteristics Level

System must have ability to:

1.2.5.1 Provide a sighting system which permits the fine aiming of turret weapons during day/night normal operations (day/night sight)

1.2.5.2 Provide a sighting system which permits the gross aiming of turret weapons (vane sight)

1.2.5.3 Provide a sighting system which permits the aiming at ground targets

1.2.5.4 Provide a sighting system which permits the aiming at aerial targets

Carrier Team Subsystem

1.0 System Definition

1.2 Conducting fire of weapons operation (objective level)

1.2.6 Capability to fire weapons (functional purpose level)

Characteristics Level

System must have ability to:

1.2.6.1 Provide capability to fire turret weapons from TC or Gunner Position in normal operating mode

1.2.6.2 Capability to fire turret weapons in degraded mode

Carrier Team Subsystem

1.0 System Definition

1.3 Conduct squad command and control (objective level)

1.3.1 Ability to control squad/team operations

Characteristics Level

System must have ability to:

1.3.1.1 Communicate orders.

1.3.1.2 Coordinate/monitor team actions

1.3.1.3 Override team actions

Carrier Team Subsystem

1.0 System Definition

1.3 Conduct squad command and control (objective level)

1.3.2 Ability to perform threat assessment (functional purpose level)

Characteristics Level

System must have ability to:

1.3.2.1 Determine most dangerous threat

1.3.2.2 Determine dangerous threat

1.3.2.3 Determine least dangerous threat

Carrier Team Subsystem

1.0 System Definition

1.3 Conduct squad command and control (objective level)

1.3.3 Ability to make tactical decisions (functional purpose level)

<u>Characteristics Level</u>

The system must have:

1.3.3.1 Knowledge of Co/Plt Tactical SOP

1.3.3.2 Knowledge of situation, enemy, and mission

1.3.3.3 Knowledge of tactical doctrine

1.3.3.4 Ability to make use of terrain

1.3.3.5 Ability to communicate tactical decision

1.3.3.6 Knowledge of system capabilities and its limitations

1.3.3.7 Ability to coordinate w/supporting squads

Carrier Team Subsystem

1.0 System Definition

1.3 Conduct squad command and control (objective level)

1.3.4 Ability to control squad/team engagements (functional purpose level)

<u>Characteristics Level</u>

The system must have ability to:

1.3.4.1 Determine appropriate weapon and maneuver

1.3.4.2 Communicate and control conduct of fire

1.3.4.3 Determine engagement effectiveness

1.3.4.4 Determine when to terminate engagement

Carrier Team Subsystem

1.0 System Definition

1.3 Conduct squad command and control (objective level)

1.3.5 Capability to relay platoon commands (functional purpose level)

Characteristics Level

The system must have ability to:

1.3.5.1 Receive and relay passive platoon commands (hand, arm or flag signals)

1.3.5.2 Receive and relay platoon commands via radio

Carrier Team Subsystem

1.0 System Definition

1.4 Provide squad transportation (objective level)

1.4.1 Provide for squad cross country transportation (functional purpose level)

Characteristics Level

The system must have ability to:

1.4.1.1 Transport squad over flat terrain

1.4.1.2 Transport squad over hilly/rugged terrain

1.4.1.3 Transport squad over loose/soft soil conditions

1.4.1.4 Transport squad over vegetated/unvegetated terrain

1.4.1.5 Transport squad with low to medium speed mobility

Carrier Team Subsystem

1.0 System Definition

1.4 Provide squad transportation (objective level)

1.4.2 Provide for squad tactical movements (functional purpose level)

Characteristics Level

The system must have:

1.4.2.1 Ability for squad to conduct traveling movement (contact with enemy, not likely)

1.4.2.2 Ability for squad to conduct traveling overwatch movement, contact wth enemy, possible

1.4.2.3 Ability for squad to conduct bounding overwatch movement, contact with enemy, expected.

Carrier Team Subsystem

1.0 System Definition

1.4 Provide squad transportation (objective level)

1.4.3 Provide for transportation of system (squad) TOE equipment/supplies (functional purpose level)

Characteristics Level

The system must have ability to:

1.4.3.1 Transport TOE equipment/supplies over flat terrain

1.4.3.2 Transport TOE equipment/supplies over hilly/rugged terrain

1.4.3.3 Transport TOE equipment/supplies over loose/soft soil conditions

1.4.3.4 Transport TOE equipment/supplies over vegetated/unvegetated terrain

1.4.3.5 Transport TOE equipment/supplies with low to medium speed mobility

Carrier Team Subsystem

1.0 System Definition

1.4 Provide squad transportation (objective level)

1.4.4 Provide ability to ford shallow water obstacles (functional purpose level)

Characteristics Level

The system must have ability to:

1.4.4.1 Determine that water obstacle is fordable

1.4.4.2 Ford shallow water obstacles with minimum essential preparation/ interruption of advance

1.4.4.3 Enter ford and exit obstacle in an appropriate manner

1.4.4.4 Ford water obstacle with minimum penetration and no damage due to water

1.4.4.5 Resume normal land operations after fording with minimum preparations

Carrier Team Subsystem

1.0 System Definition

1.4 Provide squad transportation (objective level)

1.4.5 Provide ability to swim across deep water obstacles (functional purpose level)

Characteristics Level

The system must have ability to:

1.4.5.1 Determine that water obstacle is appropriate for swim operation

1.4.5.2 Swim obstacle with minimum essential preparation/interruption of advance

1.4.5.3 Enter, swim and exit obstacle in an appropriate manner

1.4.5.4 Swim water with minimum penetration and no damage due to water

1.4.5.5 Resume normal land operations after swimming with minimum preparation

Carrier Team Subsystem

1.0 System Definition

1.5 Provide squad transportation (objective level)

1.5.1 Enable intra-squad radio communication (functional purpose level)

Characteristics Level

The system must have ability to:

1.5.1.1 Allow all carrier team system personnel to transmit information securely to all squad members when appropriate

1.5.1.2 Allow all carrier team system personnel to receive secure information from selected crew compartment personnel

Carrier Team Subsystem

1.0 System Definition

1.5 Provide squad transportation (objective level)

1.5.2 Enable squad/platoon radio communication (functional purpose level)

Characteristics Level

The system must have ability to:

1.5.2.1 Allow all carrier team system personnel and selected crew compartment personnel to receive information from the overwatch element

1.5.2.2 Allow selected carrier team and/or crew compartment personnel to transmit information to the overwatch element

Carrier Team Subsystem

1.0 System Definition

1.5 Provide squad transportation (objective level)

1.5.3 Enable squad/platoon communication during periods of radio silence (functional purpose level)

<u>Characteristics Level</u>

The system must have ability to:

1.5.3.1 Allow carrier team personnel to receive non-radio tactical/administrative communication

1.5.3.2 Allow carrier team personnel to transmit non-radio tactical/administrative communication

Carrier Team Subsystem

1.0 System Definition

1.6 Providing squad protection (objective level)

1.6.1 Provide armor protection against hostile fire (functional purpose level)

Characteristics Level

The system must have ability to:

1.6.1.1 Provide full armor protection against hostile small arms fire

1.6.1.2 Provide full armor protection against machine gun fire

1.6.1.3 Provide full armor protection against shell fragments

1.6.1.4 Provide varying armor protection against nuclear effects

1.6.1.5 Provide varying armor protection against automatic cannons

1.6.1.6 Provide varying armor protection against anti-armor

1.6.1.7 Provide varying armor protection against aircraft

Carrier Team Subsystem

1.0 System Definition

1.6 Providing squad protection (objective level)

1.6.2 Provide internal environmental control (functional purpose level)

Characteristics Level

The system must have ability to:

1.6.2.1 Provide for adequate internal illumination

1.6.2.2 Provide for adequate protection from the elements

1.6.2.3 Provide for adequate ventilation

1.6.2.4 Provide for adequate noise protection

Carrier Team Subsystem

1.0 System Definition

1.6 Providing squad protection (objective level)

1.6.3 Provide for life support (functional purpose level)

<u>Characteristics Level</u>

The system must have ability to:

1.6.3.1 Provide for adequate storage of sufficient rations

1.6.3.2 Provide for adequate storage of sufficient water

1.6.3.3 Provide for adequate storage of medical supplies

1.6.3.4 Provide for adequate fire extinguishing equipment

1.6.3.5 Provide for personal flotation devices

Carrier Team Subsystem

2.0 Mission Requirements (Objective Level)

The system must be able to:

2.1 Perform overwatch bounding element duties in response to platoon movement order

2.2 Conduct air/ground surveillance within assigned sectors

2.3 Conduct threat engagement of identified threat(s)

2.4 Conduct appropriate communications as required by mission

Carrier Team Subsystem

2.0 Mission Requirements

2.1 Perform overwatch bounding element duties in response to platoon movement order (objective level)

2.1.1 Bound to secure forward position (functional purpose level)

Characteristics Level

System must be able to:

2.1.1.1 Select an appropriate bound position

2.1.1.2 Select an appropriate bound route

2.1.1.3 Perform the bound over the route

2.1.1.4 Occupy the bound position

2.1.2 Enable platoon movement (functional purpose level)

Characteristics Level

System must be able to:

2.1.2.1 Determine that the bound position is secure

2.1.2.2 Communicate that the overwatch element can proceed to the bound position

2.1.2.3 Provide security to the overwatch element during advance

Carrier Team Subsystem

2.0 Mission Requirements

2.2 Conduct air/ground surveillance within assigned sectors (objective level)

2.2.1 Locate threat signatures (functional purpose level)

Characteristics Level

System must be able to:

2.2.1.1 Detect threat signature, e.g. signatures of track vehicles, anti-tank guided missiles, artillery, aircraft, soldiers, etc.

2.2.1.2 Identify threat signatures, e.g., as above

2.2.2 Locate likely threat avenues of approach/positions (functional purpose level)

Characteristics Level

System must be able to:

2.2.2.1 Assess terrain to identify likely avenues of approach/positions

2.2.2.2 Classify likely avenues of approach/position in terms of the degree of likely threat to squad/platoon/mission

2.2.3 Locate actual threats (functional purpose level)

Characteristics Level

System must be able to:

2.2.3.1 Detect actual threats, e.g. track vehicles, wheeled vehicles, ATGM's, artillery, personnel, aircraft, etc.

2.2.3.2 Identify actual threats, track vehicles, wheeled vehicles, ATGM's Artillery, personnel, aircraft, etc.

2.2.3.3 Classify actual threats in terms of degree of threat to squad/platoon/mission

Carrier Team Subsystem

2.0 Mission Requirements

2.3 Conduct threat engagement of identified threat(s) (objective level)

2.3.1 Engage and destroy/neutralize/suppress threats along the axis of squad/platoon advance that have not detected platoon presence (functional purpose level)

<u>Characteristics Level</u>

System must be able to:

2.3.1.1 Communicate warning of threat presence

2.3.1.2 Determine and occupy an appropriate firing position

2.3.1.3 Determine appropriate weapons against threat

2.3.1.4 Conduct and control system weapon fire

2.3.1.5 Determine effectiveness of weapon's fire

2.3.1.6 Cease fire when desired effect has been achieved without over-expending resources

2.3.2 Engage to destroy/neutralize/suppress threats that are conducting, are about to conduct hostile operations against system or overwatch element. (functional purpose level)

<u>Characteristics Level</u>

System must be able to:

2.3.2.1 Take appropriate maneuvering action

2.3.2.2 Determine and occupy an appropriate firing position

2.3.2.3 Determine appropriate weapon against threat

2.3.2.4 Conduct and control system weapon fire to gain fire superiority

2.3.2.5 Coordinate firing with platoon headquarters

2.3.2.6 Determine effectiveness of weapon's fire

2.3.2.7 Cease fire when desired effect has been achieved without overexpending resources

Carrier Team Subsystem

2.0 Mission Requirements

2.4 Conduct appropriate communications as required by mission (Objective level)

2.4.1 Coordinate platoon/squad movement (functional purpose level)

Characteristics Level

System must be able to:

2.4.1.1 Receive movement instructions from platoon

2.4.1.2 Transmit movement instructions

2.4.2 Exchange intelligence information with squad/platoon (functional purpose level)

Characteristics Level

System must be able to:

2.4.2.1 Report observations of threats, threat signatures, and likely approaches/positions of threats to platoon

2.4.2.2 Receive factual intelligence information from platoon

2.4.3 Exchange intra-squad information (functional purpose le\ `)

Characteristics Level

System must be able to:

2.4.3.1 Permit the intelligible exchange of necessary administrative and tactical information among the carrier team system personnel

2.4.3.2 Permit the intelligible exchange of necessary administrative and tactical information between the carrier team system and the crew compartment system

Carrier Team Subsystem

2.0 Mission Requirements

2.4 Conduct appropriate communications as required by mission (objective level)

2.4.4 Coordinate squad/platoon conduct of fire operations (functional purpose level)

Characteristics Level

System must be able to:

2.4.4.1 Receive conduct of fire information from platoon/other squads

2.4.4.2 Transmit conduct of fire information to platoon/other squads

3.0 Environment Specification (Objective Level)

The system must:

3.1 Operate over rolling terrain

3.2 Operate over various rural and agricultural land areas

3.3 Operate in the presence of indigenous obstacles

3.4 Operate in summer, fair weather in Southern Germany

3.0 Environment specifications

3.1 Operate over rolling terrain (objective level)

3.1.1 Operate over hills (functional purpose level)

Characteristics Level

3.1.1.1 Operate over a maximum upslope up to eight degrees

3.1.1.2 Operate over an upgrade whose length does not exceed 250 meters

3.1.2 Operate over valleys (functional purpose level)

Characteristics Level

3.1.2.1 Operate over a maximum downslope up to eight degrees

3.1.2.2 Operate over a maximum downslope up to 1000 meters

3.1.3 Operate over flat terrain (functional purpose level)

Characteristics Level

3.1.3.1 Operate over terrain which has little or no change in elevation

3.1.3.2 Operate over a maximum area of flat terrain up to 1000 meters

Carrier Team Subsystem

3.0 Environment specifications

3.2 Operate over various rural and agricultural land areas (objective level)

3.2.1 Operate over land area with fields (functional purpose level)

Characteristics Level

3.2.1.1 Operate over an open uncultivated grassy land area (not plowed)

3.2.1.2 Operate over an open cultivated land area (plowed)

3.2.2 Operate over land area with roads (functional purpose level)

Characteristics Level

3.2.2.1 Operate over secondary roads (paved)

3.2.2.2 Operate over light duty roads (dirt)

3.2.2.3 Operate over trails

3.2.3 Operate over land area with farms (functional purpose level)

Characteristics Level

3.2.3.1 Operate in the presence of land areas utilized for the raising of livestock

3.2.3.2 Operate in the presence of land areas utilized for the raising of agricultural crops

3.2.4 Operate over land areas with forests (functional purpose level)

Characteristics Level

3.2.4.1 Operate over land areas covered with deciduous trees

3.2.4.2 Operate over land areas covered with coniferous trees

3.2.4.3 Operate over land areas covered with mixed deciduous and coniferous trees.

Carrier Team Subsystem

3.0 Environment specification

3.3 Operate in the presence of indigenous obstacles (objective level)

3.3.1 Bypass dry stone walls (functional purpose level)

Characteristics Level

3.3.1.1 Bypass stone walls that are more than 1-1/2 meters high

3.3.1.2 Bypass stone wall less than 1-1/2 meters high where there is an opening within 25 meters of desired route

3.3.2 Bypass rocky outcroppings (functional purpose level)

Characteristics Level

3.3.2.1 Bypass boulder more than 1/2 meter high judged to be large

3.3.2.2 Bypass jagged rocks

3.3.3 Bypass marshy/swampy areas (functional purpose level)

Characteristics Level

3.3.3.1 Bypass untrafficable marshy/swampy land areas

3.3.3.2 Bypass any kind of soft terrain if hard surface soil is within 25 meters of desired route

3.3.4 Maneuver around trees (functional purpose level)

Characteristics Level

3.3.4.1 Maneuver around all trees of a diameter 4" or more.

3.3.4.2 Maneuver around any tree whenever an open route is within 3 meters

Carrier Team Subsystem

3.0 Environment specification

3.3 Operate in the presence of indigenous obstacles (objective level)

3.3.5 Maneuver around wide trenches (functional purpose level)

Characteristics Level

3.3.5.1 Maneuver around all trenches that are more than 2-1/2 meters wide and more than 1 meter deep

3.3.5.2 Maneuver around all trenches that extend less than 25 meters from desired route

Carrier Team Subsystem

3.0 Environment specifications

3.4 Operate in summer, fair weather in Southern Germany (objective level)

3.4.1 Operate in warm to hot temperate zone environment (functional purpose level)

Characteristics Level

3.4.1.1 Operate in temperatures ranging from 27° to 32° C

3.4.1.2 Operate in low to moderate humidity

3.4.2 Operate in daylight (functional purpose level)

Characteristics Level

3.4.2.1 Conduct operations in morning hours beginning 15 minutes after sunrise concluding at noon

3.4.2.2 Conduct operations under mostly sunny conditions

3.4.3 Operate without any precipitation (functional purpose level)

Characteristics Level

3.4.3.1 Operate in dry climatic conditions

3.4.3.2 Operate in dusty environment

3.4.4 Operate with good visibility (functional purpose level)

Characteristics Level

3.4.4.1 Operate with a visibility limited only by terrain and obstacle masking

3.4.4.2 Operate with sun glare toward East-Northeast during early morning hours

Carrier Team Subsystem

4.0 General Constraints (Objective Level)

The system must:

4.1 Maximize surveillance within the surveillance constraints

4.2 Maximize inter-intra communications within the communication constraints

4.3 Carry out tactical movements within the movement constraints

4.4 Carry out mission requirements within equipment and personnel constraints

4.5 Carry out mission requirements within threat constraints

4.6 Carry out mission requirements within weapon constraints

Carrier Team Subsystem

4.0 General Constraints

4.1 Maximize surveillance within the surveillance constraints (objective level)

4.1.1 Provide for continuous surveillance, ground and air, throughout assigned sector (functional purpose level)

Characteristics Level

4.1.1.1 Scan throughout sector unaided vision

4.1.1.2 Scan throughout sector aided vision

4.1.1.3 Scan throughout sector popped hatch

4.1.1.4 Scan throughout sector hatch down via vision blocks

4.1.2 Provide for observation of likely threat (functional purpose level)

Characteristics Level

4.1.2.1 Identify those locations within the assigned sector that are likely to conceal threats

4.1.2.2 Train surveillance attention on locations that are likely to conceal threats with aid/unaided vision

4.1.2.2 Aim turret weapons on locations that are likely to conceal threats

Carrier Team Subsystem

4.0 General Constraints

4.2 Maximize inter-intra communications within the communication constraints (objective level)

4.2.1 Maintain communication security (functional purpose level)

<u>Characteristics Level</u>

4.2.1.1 Avoid radio transmission before contact

4.2.1.2 Use of hand/arm/flag signals with external systems

4.2.1.3 Maintain light and noise discipline

4.2.2 Exchange command and control information with platoon (-) (functional purpose level)

<u>Characteristics Level</u>

4.2.2.1 Exchange vehicle movement information

4.2.2.2 Exchange intelligence information

4.2.2.3 Exchange squad/platoon system status information

4.2.3 Exchange command and contact information within the carrier team system (functional purpose level)

<u>Characteristics Level</u>

4.2.3.1 Exchange information required to command and control vehicle

4.2.3.2 Exchange command and control information with regard to surveillance of assigned sectors

4.2.3.3 Provide command and control of turret weapons

4.2.3.3 Maintain intercom discipline

Carrier Team Subsystem

4.0 General Constraints

4.2 Maximize inter-intra communications within the communication constraints (objective level)

4.2.4 Exchange command and control information with squad compartment crew (functional purpose level)

Characteristics Level

4.2.4.1 Exchange surveillance information

4.2.4.2 Exercise command and control of FPW operations

4.2.4.3 Coordinate turret weapons support requirements

4.2.4.4 Maintain intercom discipline with crew

Carrier Team Subsystem

4.0 General Constraints

4.3 Carry out tactical movements within the movement constraints (objective level)

4.3.1 Stay within squad sector during movement (functional purpose level)

Characteristics Level

4.3.1.1 Knowledge of sector limits

4.3.1.2 Control vehicle within squad/platoon limits

4.3.2 Maintain reasonable visual contact with platoon (-) (overwatch element)

Characteristics Level

4.3.2.1 Stay within visual communication sources

4.3.2.2 Maximize visibility of route of advance to platoon (-)

4.3.3 Minimize system signature

Characteristics Level

4.3.3.1 Utilize maximum cover and concealment from likely threats

4.3.3.2 Avoid "skylining"

4.3.3.3 Minimize vehicle smoke and dust signatures

4.3.4 Maintain movement speed consistent with the movement order considering squad order

Characteristics Level

4.3.4.1 Maintain average speed consistent with movement plan and hostile action

4.3.4.2 Achieve a speed consistent with low vehicle signature requirements

4.3.4.3 Achieve speed over terrain consistent with the mission requirements which will not jeopardize crew safety or result in damaged equipment.

Carrier Team Subsystem

4.0 General Constraints

4.3 Carry out tactical movements within the movement constraints (objective level)

4.3.5 Execute bound to maximize weapon support from platoon (-) (functional purpose level)

Characteristics Level

4.3.5.1 Bound distance should not exceed overwatch element weapon support

4.3.5.2 Bound positions must be visible to the overwatch element

Carrier Team Subsystem

4.0 General Constraints

4.4 Carry out mission requirements within equipment and personnel constraints (objective level)

4.4.1 Carry out mission requirement with system personnel constraints (functional purpose level)

Characteristics Level

4.4.1.1 Operate with the authorized number of carrier team personnel

4.4.1.2 Operate with MOS qualified personnel

4.4.1.3 Operate with personnel whose physical size meets system anthropometric design limits

4.4.2 Carry out mission requirement with system TOE equipment (functional purpose level)

Characteristics Level

4.4.2.1 Operate with only the authorized TOE equipment

4.4.2.2 Utilize applicable TOE equipment for appropriate purpose

4.4.2.3 Operate equipment properly throughout mission

Carrier Team Subsystem

4.0 General Constraints

4.5 Carry out mission requirements within threat constraints (objective level)

4.5.1 Conduct operations to neutralize threats effectively, when appropriate (functional purpose level)

Characteristics Level

4.5.1.1 Bring appropriate firepower to bear

4.5.1.2 Minimize system exposure

4.5.2 Evade threats effectively, when appropriate

Characteristics Level

4.5.2.1 Deny the threat the ability to engage the carrier team system

4.5.2.2 Preserve system integrity

4.5.2.3 Preserve mission integrity

Carrier Team Subsystem

4.0 General Constraints

4.6 Carry out mission requirements within weapon cons' airts (objective level)

4.6.1 Fire weapons only within assigned sector (functional purpose level)

Characteristics Level

4.6.1.1 Maintain knowledge of sector boundaries

4.6.1.2 Maintain knowledge of support forces

4.6.2 Fire weapons employing safe fire rates

Characteristics Level

4.6.2.1 Employ fire rate consistent with safe weapon operations

4.6.2.2 Employ a fire rate consistent with effective engagement of the target

Carrier Team Subsystem

5.0 General Performance Requirements (Objective Level)

The system must be able to:

5.1 Perform squad bound

5.2 Detect threats

5.3 Engage threats

Carrier Team Subsystem

5.0 Performance Requirements

5.1 Perform squad bound (objective level)

5.1.1 Provide for platoon security (functional purpose level)

Characteristics Level

5.1.1.1 Occupy bound position to afford maximum fields of fire

5.1.1.2 Communicate that bound position is secure to overwatch element

5.1.1.3 Provide covering fire, when appropriate in support of overwatch element advance

5.1.2 Advance toward the objectives (functional purpose level)

Characteristics Level

5.1.2.1 Select an approximate bound route

5.1.2.2 Select and control an appropriate vehicle speed

Carrier Team Subsystem

5.0 Performance Requirements

5.2 Detect threats (objective level)

5.2.1 Locate the enemy (functional purpose level)

Characteristics Level

5.2.1.1 Observe surveillance area for threat signatures

5.2.1.2 Observe surveillance areas for actual threats

5.2.2 Provide Intelligence Information (functional purpose level)

Characteristics Level

5.2.2.1 Information regarding what was observed

5.2.2.2 Information regarding how many observed

5.2.2.3 Information regarding where and when observed

5.2.2.4 Information regarding what enemy was doing

5.2.3 Formulate tactical decisions (functional purpose level)

Characteristics Level

5.2.3.1 Degree of threat to squad/platoon

5.2.3.2 System Capability, vis-a-vis, the threat

5.2.3.3 Degree the threat is a jeopardy to the mission

Carrier Team Subsystem

5.0 Performance Requirements

5.3 Engage threat (objective level)

5.3.1 Destroy/neutralize the threat (functional purpose level)

<u>Characteristics Level</u>

5.3.1.1 Take appropriate action for self preservation

5.3.1.2 Produce effective conduct of fire operations

5.3.1.3 Hit the threat with appropriate ammunition

5.3.1.4 Assess correctly when threat has been destroyed/neutralized

5.3.1.5 Cease fire when appropriate

5.3.2 Self protection (functional purpose level)

<u>Characteristics Level</u>

5.3.2.1 Minimize system profile

5.3.2.2 Use firepower to deny threat conduct of fire operations

5.3.2.3 Effective use of camouflage and concealment

5.3.2.4 Request supporting fires

5.3.3 Seize the advantage of the situation (functional purpose level)

<u>Characteristics Level</u>

5.3.3.1 Achieve control of the terrain

5.3.3.2 Reduce or neutralize threat offensive capability

5.3.3.3 Gain tactical superiority

5.3.3.4 Reduce or neutralize threat defensive capability

Carrier Team Subsystem

5.0 Performance Requirements

5.3 Engage threat (objective level)

5.3.4 Deny the enemy the advantage of the situation (functional purpose level)

Characteristics Level

5.3.4.1 Maintain system offensive capability

5.3.4.2 Maintain system defensive capability

5.3.4.3 Maintain control of the terrain

5.3.4.4. Maintain tactical superiority

6.0 General Performance Criteria (Objective Level)

The system must be able to:

6.1 Achieve an appropriate bound position, distance and time

6.2 Detect all targets within sector, without false detections

6.3 Engage successfully all appropriate targets within sector, with minimum expenditure of time and resources

Carrier Team Subsystem

6.0 General Performance Criteria

6.1 Achieve an appropriate bound position, distance and time (objective level)

6.1.1 Bound position must provide optimum forward security for overwatch element (functional purpose level)

<u>Characteristics Level</u>

The system must:

6.1.1.1 Provide maximum effective fields of fire for all system weapons

6.1.1.2 Afford the means to communicate the forward movement of the overwatch element consistent with communication constraints

6.1.1.3 Provide appropriate, timely, and effective covering fire to support overwatch elements advance

6.1.2 Bound position must provide an efficient advance toward mission objectives (functional purpose level)

<u>Characteristics Level</u>

The system must:

6.1.2.2 Afford as direct an advance toward bound position as possible, consistent with all applicable constraints

6.1.2.2 Afford as rapid an advance toward bound position as possible consistent with all applicable constraints

Carrier Team Subsystem

6.0 General Performance Criteria

6.2 Detect all threats within sector, without false detections (objective level)

6.2.1 Locate all threats within sector in a timely fashion (functional purpose level)

Characteristics Level

The system must:

6.2.1.1 Locate and recognize threat signatures quickly and accurately

6.2.1.2 Locate and recognize actual threats quickly and accurately

6.2.2 Provide accurate, complete intelligence information consistent with the mission (functional purpose level)

Characteristics Level

The system must:

6.2.2.1 Provide accurate, timely, and useful information concerning what was observed

6.2.2.2 Provide accurate, timely, and useful information concerning how many were observed

6.2.2.3 Provide accurate, timely, and useful information concerning where and when the observations were made

6.2.2.4 Provide accurate, timely, and useful information concerning what the enemy was doing

Carrier Team Subsystem

6.0 General Performance Criteria

6.2 Detect all threats within sector, without false detections (objective level)

6.2.3 Formulate appropriate and timely tactical decisions concerning detection of threats (functional purpose level)

Characteristics Level

The system must:

6.2.3.1 Provide accurate and timely assessment of the degree of threat to squad and platoon

6.2.3.2 Provide accurate assessment of system status and system capabilities as well as threat's capabilities

6.2.3.3 Provide accurate assessment of the degree the threat is a jeopardy to the mission

Carrier Team Subsystem

6.0 General Performance Criteria

6.3 Engage successfully all appropriate targets within sector, with minimum expenditure of time and resources (objective level)

6.3.1 Destroy/neutralize threats, when appropriate, in a timely and efficient manner (functional purpose level)

Characteristics Level

The system must:

6.3.1.1 Maximize self-preservation while conducting effective weapon fire operations

6.3.1.2 Direct and produce accurate, timely conduct of fire to destroy/neutralize the threat

6.3.1.3 Hit the threat with appropriate ammunition, type and amount, in order to destroy/neutralize threat

6.3.1.4 Assess accurately and timely threat destruction/neutralization

6.3.1.5 Cease fire upon successful destruction/neutralization of the threat

6.3.2 Engage sucessfully all appropriate threats in a timely and efficient manner to provide for self protection (functional purpose level)

Characteristics Level

The system must:

6.3.2.1 Expose the smallest possible profile to the threat while maintaining system weapons capabilities

6.3.2.2 Produce weapon fire sufficient to deny the threat's ability to produce effective weapons fire operations

6.3.2.3 Make proper use of available camouflage and concealment to deny the threat's ability to produce effective weapon's fire operations

6.3.2.4 Request supporting fire that are appropriate, timely, accurate, and complete

Carrier Team Subsystem

6.0 General Performance Criteria

6.3 Engage successfully all appropriate targets within sector, with minimum expenditure of time and resources (objective level)

6.3.3 Seize the advantage of the situation by efficient use of terrain and system capabilities (functional purpose level)

Characteristics Level

The system must:

6.3.3.1 Establish and maintain fire superiority over the likely avenues of approach

6.3.3.2 Use system weapon and maneuver capabilities and terrain so as to deny threat's abilities to conduct effective offensive operations

6.3.3.3 Use system weapons, maneuverability and terrain to gain fire superiority in order to reduce/neutralize threats defensive capabilities

APPENDIX B - CREW COMPARTMENT TEAM TAXONOMIES

Crew Compartment Team Subsystem

1.0 System Definition (Objective Level)

The crew compartment team must be capable of:

1.1 Providing for crew compartment team surveillance

1.2 Conducting fire of weapons operations

1.3 Providing for crew compartment team command and control

1.4 Providing for crew compartment transportation

1.5 Providing for squad and platoon communications

1.6 Providing for squad protection

Crew Compartment Team Subsystem

1.0 System Definition

1.1 Providing for crew compartment team surveillance (objective level)

1.1.1 Conduct sector surveillance (functional purpose level)

Characteristics Level

System must have ability to:

1.1.1.1 Conduct visually ground sector surveillance in through vision blocks on left side of crew compartment

1.1.1.2 Conduct visually ground sector surveillance through vision blocks on right side of crew compartment

1.1.1.3 Conduct visually ground sector surveillance through vision blocks on rear side of crew compartment

1.1.2 Ability to detect targets (functional purpose level)

Charactistics Level

System must have ability to:

1.1.2.1 Detect visually ground target signatures

1.1.2.2 Detect visually ground target

1.1.3 Ability to identify targets (functional purpose level)

Characteristics Level

System must have ability to:

1.1.3.1 Identify the following type targets visually through vision blocks at a visibility range of 1000 meters (vehicle stationary)

- Tank
- BMP
- ATGM
- Arty
- Wheeled vehicle
- CP area
- Personnel
- Aircraft
- Bunker
- Etc.

Crew Compartment Team Subsystem

1.0 System Definition

1.1 Providing for crew compartment team surveillance (objective level)

1.1.1 Conduct sector surveillance (functional purpose level)

Characteristics Level

System must have ability to:

1.1.1.1 Conduct visually ground sector surveillance in through vision blocks on left side of crew compartment

1.1.1.2 Conduct visually ground sector surveillance through vision blocks on right side of crew compartment

1.1.1.3 Conduct visually ground sector surveillance through vision blocks on rear side of crew compartment

1.1.2 Ability to detect targets (functional purpose level)

Charactistics Level

System must have ability to:

1.1.2.1 Detect visually ground target signatures

1.1.2.2 Detect visually ground target

1.1.3 Ability to identify targets (functional purpose level)

Characteristics Level

System must have ability to:

1.1.3.1 Identify the following type targets visually through vision blocks at a visibility range of 1000 meters (vehicle stationary)

- **Tank**
- **BMP**
- **ATGM**
- **Arty**
- **Wheeled vehicle**
- **CP area**
- **Personnel**
- **Aircraft**
- **Bunker**
- **Etc.**

Crew Compartment Team Subsystem

1.0 System Definition

1.1 Providing for crew compartment team surveillance (objective level)

1.1.3.2 Identify the following type targets visually through vision blocks of a visibility range of 1500 meters

- Tank
- BMP
- Arty
- Wheeled vehicle

Crew Compartment Team Subsystem

1.0 System Definition

1.2 Conducting fire of weapons operations (objective level)

1.2.1 Ability to conduct firing port weapons operations (functional purpose level)

<u>Characteristics Level</u>

System must have ability to:

1.2.1.1 Estimate range to ground targets

1.2.1.2 Control firing rate of FPW's

1.2.1.3 Observe and correct bursts on target

1.2.1.4 Load/reload FPW's

1.2.1.5 Determine when target has been suppressed/destroyed/neutralized

Crew Compartment Team Subsystem

1.0 System Definition

1.3 Providing for crew compartment team command and control (objective level)

1.3.1 Ability to control team operations

Characteristics Level

System must have ability to:

1.3.1.1 Communicate orders

1.3.1.2 Coordinate/monitor team actions

1.3.2 Ability to perform threat assessment (functional purpose level)

Characteristics Level

System must have ability to:

1.3.2.1 Determine most dangerous threat

1.3.2.2 Determine dangerous threat

1.3.2.3 Determine least dangerous threat

1.3.3 Ability to make tactical decisions (functional purpose level)

Characteristics Level

System must have:

1.3.3.1 Knowledge of Plt Tactical SOP

1.3.3.2 Knowledge of situation, enemy, and mission

1.3.3.3 Knowledge of tactical doctrine

1.3.3.4 Ability to communicate tactical decision

1.3.3.5 Knowledge of system capabilities and its limitations

Crew Compartment Team Subsystem

1.0 System Definition

1.3 Providing for crew compartment team command and control (objective level)

1.3.4 Ability to control team engagements (functional purpose level)

Characteristics Level

System must have ability to:

1.3.4.1 Communicate and control conduct of fire

1.3.4.2 Determine engagement effectiveness

1.3.4.3 Determine when to terminate engagement

Crew Compartment Team Subsystem

1.0 System Definition

1.4 Provide crew compartment transportation (objective level)

1.4.1 Provide for transportation of system TOE equipment/supplies (functional purpose level)

Characteristics Level

System must have ability to:

1.4.1.1 Transport TOE equipment/supplies over flat terrain

1.4.1.2 Transport TOE equipment/supplies over hilly/rugged terrain

1.4.1.3 Transport TOE equipment/supplies over loose/soft soil conditions

1.4.1.4 Transport TOE equipment/supplies over vegetated/unvegetated terrain

1.4.1.5 Transport TOE equipment/supplies with low to medium speed mobility

Crew Compartment Team Subsystem

1.0 System Definition

1.5 Providing for squad and platoon communications (objective level)

1.5.1 Enable intra-squad radio communication (functional purpose level)

Characteristics Level

System must have ability to:

1.5.1.1 Allow selected crew compartment team system personnel to transmit information securely to all squad members when appropriate

1.5.1.2 Allow all crew compartment personnel to receive secure information from any carrier team member

1.5.2 Enable squad/platoon radio communication (functional purpose level)

Characteristics Level

System must have ability to:

1.5.2.1 Allow selected crew compartment personnel to receive information from the overwatch element

1.5.2.2 Allow selected crew compartment personnel to transmit information to the overwatch element

Crew Compartment Team Subsystem

1.0 System Definition

1.6 Providing for squad protection (objective level)

1.6.1 Provide armor protection against hostile fire (functional purpose level)

<u>Characteristics Level</u>

System must have ability to:

1.6.1.1 Provide full armor protection against hostile small arms fire

1.6.1.2 Provide full armor protection against machine gun fire

1.6.1.3 Provide full armor protection against shell fragments

1.6.1.4 Provide varying armor protections against nuclear effects

1.6.1.5 Provide varying armor protection against automatic cannons

1.6.1.6 Provide varying armor protection against anti-armor

1.6.1.7 Provide varying armor protection against aircraft

1.6.2 Provide internal environmental control (functional purpose level)

<u>Characteristics Level</u>

System must have ability to:

1.6.2.1 Provide for adequate internal illumination

1.6.2.2 Provide for adequate protection from the elements

1.6.2.3 Provide for adequate ventilation

1.6.2.4 Provide for adequate noise protection

Crew Compartment Team Subsystem

1.0 System Definition

1.6 Providing crew compartment protection (objective level)

1.6.3 Provide for life support (functional purpose level)

Characteristics Level

System must have ability to:

1.6.3.1 Provide for adequate storage of sufficient rations

1.6.3.2 Provide for adequate storage of sufficient water

1.6.3.3 Provide for adequate storage of medical supplies

1.6.3.4 Provide for adequate fire extinguishing equipment

1.6.3.5 Provide for personal flotation devices

2.0 Mission Requirements (Objective Level)

The system must be able to:

2.1 Conduct air/ground surveillance within assigned sectors

2.2 Conduct threat engagement of identified threat(s)

2.3 Conduct appropriate communications as required by mission

Crew Compartment Team Subsystem

2.0 Mission Requirements

2.1 Conduct ground surveillance within assigned sectors (objective level)

2.1.1 Locate threat signatures (functional purpose level)

Characteristics Level

System must be able to:

2.1.1.1 Detect threat signature, e.g. signatures of track vehicles, anti-tank guided missiles, artillery, aircraft, soldiers, etc.

2.1.1.2 Identify threat signatures, e.g., as above

2.1.2 Locate likely threat positions (functional purpose level)

Characteristics Level

System must be able to:

2.1.2.1 Assess terrain to identify likely positions

2.1.2.2 Classify likely position in terms of the degree of likely threat to squad/platoon/mission

2.1.3 Locate actual threats (functional purpose level)

Characteristics Level

System must be able to:

2.1.3.1 Detect actual threats, e.g. track vehicles, wheeled vehicles, ATGM's, artillery, personnel, aircraft, etc.

2.1.3.2 Identify actual threats, track vehicles, wheeled vehicles, ATGM's artillery, personnel, aircraft, etc.

2.1.3.3 Classify actual threats in terms of degree of threat to squad/platoon/mission

Crew Compartment Team Subsystem

2.0 Mission Requirements

2.3 Conduct appropriate communications as required by mission (objective level)

2.3.1 Exchange intelligence information with squad (functional purpose level)

Characteristics Level

System must be able to:

2.3.1.1 Report observations of threats, threat signatures, and likely approaches/positions of threats to squad leader

2.3.1.2 Receive factual intelligence information from squad

2.3.2 Exchange intra-squad information (functional purpose level)

Characteristics Level

System must be able to:

2.3.2.1 Permit the intelligible exchange necessary administrative and tactical information with the carrier team system personnel

2.3.2.2 Permit the intelligible exchange of necessary administrative and tactical information between the crew compartment system

2.3.3 Coordinate squad/platoon conduct of fire operations (functional purpose level)

Characteristics Level

System must be able to:

2.3.3.1 Receive conduct of fire information from platoon/other squads

2.3.3.2 Transmit conduct of fire information to platoon/other squads

Crew Compartment Team Subsystem

2.0 Mission Requirements

2.2 Conduct threat engagement of identified threat(s) (objective level)

2.2.1 Engage and destroy/neutralize/suppress "soft" threats along the axis of squad/platoon advance that have not detected platoon presence (functional purpose level)

Characteristics Level

System must be able to:

2.2.1.1 Communicate warning of threat presence

2.2.1.2 Determine that firing port weapons are appropriate against threat

2.2.1.3 Conduct and control system weapon fire

2.2.1.4 Determine effectiveness of weapons' fire

2.2.1.5 Cease fire when desired effect has been achieved without overexpending resources

2.2.2 Engage to destroy/neutralize/suppress "soft" threats that are conducting, are about to conduct hostile operations against system or overwatch element. (functional purpose level)

Characteristics Level

System must be able to:

2.2.2.1 Communicate warning of threat presence

2.2.2.2 Determine that firing port weapons are appropriate against threat

2.2.2.3 Conduct and control system weapon fire to gain fire superiority

2.2.2.4 Determine effectiveness of weapon's fire

2.2.2.5 Cease fire when desired effect has been achieved without overexpending resources

3.0 Environment Specification (Objective Level)

The system must:

3.1 Operate in summer, fair weather in Southern Germany

Crew Compartment Team Subsystem

3.0 Environment Specification

3.1 Operate in summer, fair weather in Southern Germany (objective level)

3.1.1 Operate in warm to hot temperate zone environment (functional purpose level)

Characteristics Level

System must be able to:

3.1.1.1 Operate in temperatures ranging from 27° to 32° C

3.1.1.2 Operate in low to moderate humidity

3.1.2 Operate in daylight (functional purpose level)

Characteristics Level

System must be able to:

3.1.2.1 Conduct operations in morning hours beginning 15 minutes after sunrise concluding at noon

3.1.2.2 Conduct operations under mostly sunny conditions

3.1.3 Operate without any precipitation (functional purpose level)

Characteristics Level

System must be able to:

3.1.3.1 Operate in dry climatic conditions

3.4.3.2 Operate in dusty environment

3.1.4 Operate with good visibility (functional purpose level)

Characteristics Level

System must be able to:

3.1.4.1 Operate with a visibility limited only by terrain and obstacle masking

3.1.4.2 Operate with sun glare toward East-Northeast during early morning hours

4.0 General Constraints (Objective Level)

The system must:

4.1 Maximize surveillance within the surveillance constraints

4.2 Maximize inter-intra communications within the communication constraints

4.3 Carry out mission requirements within equipment and personnel constraints

4.4 Carry out mission requirements within threat constraints

4.5 Carry out mission requirements within weapon constraints

Crew Compartment Team Subsystem

4.0 General Constraints

4.1 Maximize surveillance within the surveillance constraints (objective level)

4.1.1 Provide for continuous ground surveillance throughout assigned sector (functional purpose level)

Characteristics Level

System must be able to:

4.1.1.1 Scan throughout sector unaided vision, popped cargo hatch

4.1.1.2 Scan throughout sector hatch down via vision blocks

4.1.2 Provide for observation of likely threat areas (functional purpose level)

Characteristics Level

System must be able to:

4.1.2.1 Identify those locations within the assigned sector that are likely to conceal threats

4.1.2.2 Train surveillance attention on locations that are likely to conceal threats with unaided vision (vision blocks)

4.1.2.3 Aim firing port weapons on locations that are likely to conceal threats

Crew Compartment Team Subsystem

4.0 General Constraints

4.2 Maximize inter-intra communications within the communication constraints (objective level)

4.2.1 Maintain communication security (functional purpose level)

Characteristics Level

System must be able to:

4.2.1.1 Avoid radio transmission before contact

4.2.1.2 Maintain light and noise discipline

4.2.2 Exchange command and control information with carrier team (-) (functional purpose level)

Characteristics Level

System must be able to:

4.2.2.1 Exchange lateral vehicle movement information

4.2.2.2 Exchange intelligence information

4.2.2.3 Exchange squad/platoon system status information

4.2.2.4 Maintain intercom discipline

4.2.3 Exchange command and control information with squad compartment crew (functional purpose level)

Characteristics Level

System must be able to:

4.2.3.1 Exchange surveillance information

4.2.3.2 Exercise command and control of FPW operations

4.2.3.3 Coordinate turret weapons support requirements (reload of turret weapons)

Crew Compartment Team Subsystem

4.0 General Constraints

4.3 Carry out mission requirements within equipment and personnel constraints (objective level)

4.3.1 Carry out mission requirement with system personnel constraints (functional purpose level)

Characteristics Level

System must be able to:

4.3.1.1 Operate with the authorized number of new compartment team personnel

4.3.1.2 Operate with MOS qualified personnel

4.3.1.3 Operate with personnel whose physical size meets system anthropometric design limits

4.3.2 Carry out mission requirement with system TOE equipment (functional purpose level)

Characteristics Level

System must be able to:

4.3.2.1 Operate with only the authorized TOE equipment

4.3.2.2 Utilize applicable TOE equipment for appropriate purpose

4.3.2.3 Operate equipment properly throughout mission

Crew Compartment Team Subsystem

4.0 General Constraints

4.4 Carry out mission requirements within threat constraints (objective level)

4.4.1 Conduct operations to neutralize threats effectively, when appropriate (functional purpose level)

Characteristics Level

System must be able to:

4.4.1.1 Bring appropriate firepower to bear

4.4.1.2 Minimize system exposure

Crew Compartment Team Subsystem

4.0 General Constraints

4.5 Carry out mission requirements within weapon constraints (objective level)

4.5.1 Fire weapons only within assigned sector (functional purpose level)

Characteristics Level

System must be able to:

4.5.1.1 Maintain knowledge of sector boundaries

4.5.1.2 Maintain knowledge of support forces

4.5.2 Fire weapons employing safe fire rates

Characteristics Level

System must be able to:

4.5.2.1 Employ fire rate consistent with safe weapon operations

4.5.2.2 Employ a fire rate consistent with effective engagement of the target

Crew Compartment Team Subsystem

5.0 General Performance Requirements (Objective Level)

The system must:

5.1 Support platoon/squad bounds

5.2 Detect threats

5.3 Engage threats

Crew Compartment Team Subsystem

5.0 General Performance Requirements

5.1 Support platoon/squad bounds (objective level)

5.1.1 Provide for platoon/squad security (functional purpose level)

Characteristics Level

System must be able to:

5.1.1.1 Provide maximum fields of fire at bound position

5.1.1.2 Provide covering fire, when appropriate, in support of overwatch element advance

Crew Compartment Team Subsystem

5.0 General Performance Requirements

5.2 Detect threats (objective level)

5.2.1 Locate the enemy (functional purpose level)

Characteristics Level

System must be able to:

5.2.1.1 Observe surveillance crew for target signatures

5.2.1.2 Observe surveillance areas for actual targets

5.2.2 Provide intelligence information (functional purpose level)

Characteristics Level

System must be able to:

5.2.2.1 Information regarding what was observed

5.2.2.2 Information regarding how many observed

5.2.2.3 Information regarding where and when observed

5.2.2.4 Information regarding what enemy was doing

Crew Compartment Team Subsystem

5.0 General Performance Requirements

5.3 Engage threats

5.3.1 Destroy/neutralize/suppress the target (functional purpose level)

Characteristics Level

System must be able to:

5.3.1.1 Take appropriate action for self preservation

5.3.1.2 Produce effective conduct of fire operations

5.3.1.3 Hit the target with appropriate ammunition

5.3.1.4 Assess correctly when target has been destroyed/neutralized/suppressed

5.3.1.5 Cease fire when appropriate

5.3.2 Self protection (functional purpose level)

Characteristics Level

System must be able to:

5.3.2.1 Minimize system exposure by staying "buttoned up"

5.3.2.2 Use firepower to deny threat conduct of fire operations

5.3.3 Seize the advantage of the situation (functional purpose level)

Characteristics Level

System must be able to:

5.3.3.1 Reduce or neutralize threat offensive capability

5.3.3.2 Gain tactical superiority

5.3.3.3 Reduce or neutralize threat defensive capability

Crew Compartment Team Subsystem

5.0 General Performance Requirements

5.3 Engage threats (objective level)

5.3.4 Deny the enemy the advantage of the situation (functional purpose level)

Characteristics Level

System must be able to:

5.3.4.1 Maintain system offensive capability

5.3.4.2 Maintain system defensive capability

5.3.4.3 Maintain tactical superiority

6.0 General Performance Criteria (Objective Level)

The crew compartment team must be able to:

6.1 Support overwatch element advance

6.2 Detect all targets within sector, without false detections

6.3 Engage successfully all appropriate targets within sector, with minimum expenditure of time and resources

Crew Compartment Team Subsystem

6.0 General Performance Criteria

6.1 Support overwatch element advance (objective level)

6.1.1 The system must provide optimum forward security for overwatch element (functional purpose level)

Characteristics Level

System must:

6.1.1.1 Provide maximum effective fields of fire for all system weapons at the bound position

6.1.1.2 Provide appropriate timely, and effective coverine fire to support overwatch element's advance

Crew Compartment Team Subsystem

6.0 General Performance Criteria

6.2 Detect all targets within sector, without false detections (objective level)

6.2.1 Locate all threats within sector in a timely fashion (functional purpose level)

Characteristics Level

System must be able to:

6.2.1.1 Locate and recognize target signautres quickly and accurately

6.2.1.2 Locate and recognize actual targets quickly and accurately

6.2.2 Provide accurate, complete intelligence information consistent with the mission (functional purpose level)

Characteristics Level

System must be able to:

6.2.2.1 Provide accurate, timely, and useful information concerning what was observed

6.2.2.2 Provide accurate, timely and useful information concerning how many were observed

6.2.2.3 Provide accurate, timely and useful information concerning where and when the observations were made

6.2.2.4 Provide accurate, timely, and useful information concerning what the enemy was doing

6.2.3 Formulate appropriate and timely tactical decisions concerning detection of threats (functional purpose level)

Characteristics Level

System must be able to:

6.2.3.1 Assess the degree of threat to squad and platoon accurately and timely

6.2.3.2 Assess accurately system status and system capabilities as well as threat's capabilities

6.2.3.3 Assess accurately degree of the threat jeopardy to the mission

Crew Compartment Team Subsystem

6.0 General Performance Criteria

6.3 Engage successfully all appropriate targets within sector, with minimum expenditure of time and resources (objective level)

6.3.1 When appropriate, destroy/nautralize/suppress target in a timely and efficient manner (functional purpose level)

Characteristics Level

System must be able to:

6.3.1.1 Maximize self-preservation while conducting effective weapon fire operations

6.3.1.2 Direct and produce accurate, timely conduct of fire to destroy/nautralize the threat

6.3.1.3 Hit the target with appropriate amount of ammunition in order to destroy/neutralize/suppress threat

6.3.1.4 Assess threat destruction/neutralization/suppression accurately and timely

6.3.1.5 Cease fire upon successful destruction/neutralization/suppression of the threat

6.3.2 Engage successfully all appropriate threats in a timely and efficient manner to provide for self protection (functional purpose level)

Characteristics Level

System must be able to:

6.3.2.1 Produce weapon fire sufficient to deny the threat's ability to produce effective weapons fire operations

6.3.2.2 Make proper use of available armor protection to deny the threat's ability to produce effective weapon's fire operations

Crew Compartment Team Subsystem

6.0 General Performance Criteria

6.3 Engage successfully all appropriate targets within sector, with minimum expenditure of time and resources (objective level)

6.3.3 Seize the advantage of the situation by efficient use of terrain and system capabilities (functional purpose level)

Characteristics Level

System must be ablt to:

6.3.3.1 Establish and maintain fire superiority over the likely threat positions

6.3.3.2 Use system weapon's capabilities to deny threat's abilities to conduct effective offensive operations

6.3.3.3 Use system weapons to gain fire superiority in order to reduce/neutralize/suppress threat's defensive capabilities