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COMPARATIVE ANATOMY OF MAINTENANCE TASKS (CAMT): A FEASIBILITY STUDY

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During the system engineering process, how does one predict the maintenance Manpower, Personnel, Training, and Safety (MPT&S) consequences of a proposed design before it materializes as a breadboard or mockup? This study proposes the use of a baseline comparison with an integral data base that is more sophisticated and powerful than currently available approaches. CAMT would define a set of component task primitives, each common to many maintenance tasks, associated with a common set of maintainer skill and comprehension requirements. Associated with each primitive would be immediately accessible data concerning typical MPT&S resources required for adequate primitive performance on a variety of tasks and systems. Methods for task primitive definition were developed, then taken into the field for testing. Task primitives were defined to cover three remove-and-replace tasks in one aircraft maintenance field (engines). A literature review showed this approach to be unique. Future studies will address electronic maintenance, data base acquisition, and reliability of the methodology.

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Preface

The Armstrong Laboratory Logistics Research Division (AL/HRGD) funded this effort via Task Order No. 5 of Air Force Contract F33615-87-D-0661. Applied Science Associates, Inc. (ASA) under subcontract to QuesTech Research Division (QTRD) of QuesTech, Inc. collected, analyzed, and presented the information in this report. QTRD, as the prime contractor, provided Total Quality Management of the product. AL/HRG provided final editing. Dr. Andrew P. Chenzoff of ASA served as Principal Investigator. David Shipton of ASA managed the field data collection. Mr. Arthur Steczkowski of QTRD served as Task Monitor. Capt Donald R. Loose of Acquisition Logistics Division conceived and managed the program.

SUMMARY

During the system engineering process, how does one predict the maintenance Manpower, Personnel, Training, and Safety (MPT&S) consequences of a proposed design before it materializes as a breadboard or mockup? This study proposes the use of a baseline comparison with an integral data base that is more sophisticated and powerful than currently available approaches.

The purpose of this study was to explore the basis for defining a set of component task primitives, each common to many maintenance tasks, associated with a common set of requisite maintainer comprehension and skill requirements. These would be defined midway between whole maintenance tasks (at which level MPT&S analysis typically occurs) and detailed task steps (at which level human engineering analysis typically occurs). Associated with each primitive would be immediately accessible data concerning typical MPT&S resources required for adequate primitive performance on a variety of tasks and systems.

The project has accomplished a selective review of related military and civilian literature to:

1. determine whether an approach similar to CAMT has been previously employed,

2. refine the CAMT concept and its proposed application, and

3. benefit from related experience of previous workers in the field.

Methods for task primitive definition and associated comprehension/skill requirements identification were developed (Phase 1). These methods were taken into the field to explore the feasibility of defining task primitives for three remove-and-replace tasks in one aircraft maintenance field (engine maintenance) and to test whether task primitives developed for one weapon system could have applicability to other weapon systems (Phase 2). This is the first of a series of studies scoping the risks, costs, and benefits of developing a comprehensive human performance data base for use during weapon system acquisition.

SECTION I. THEORY

The Requirement

Within the Weapon System Acquisition Processes (WSAP) there traditionally exists a cultural rift between engineering and Integrated Logistics Support (ILS) functions. One manifestation of this rift is the lack of an integrated approach to efficiently incorporate human performance into weapon system performance.

Engineers (including human engineers) create and configure weapon subsystems and components to meet technical specifications. Meanwhile, ILS planners (including Manpower, Personnel, and Training (MPT) planners) must adjust the military "infrastructure" to provide sufficient (human) resources to support the new weapon, once fielded. The engineers completely control a small piece of the physical universe while the logistics planners work within large bureacracies of people and materiel. Not suprisingly, the two communities of experts typically have different training, career progressions, analysis tools, and jargon. They perform their functions separately.

Logisticians traditionally perform two functions in the WSAP. First, during early weapon system requirements specification, they levy hard infrastructure constraints within which the weapon system must function (e.g., the number of levels of maintenance, compatibility with existing ground support equipment, or the requirement to be repairable with common hand tools). Second, as engineers evolve supportability requirements during tradeoff studies and system design, logisticians provide advanced planning to meet these requirements (e.g., ordering long-lead-time spares, preparing facilities, or acquiring technical data).

Specifically for human performance requirements, MPT planners might first levy maximum allocations of maintenance personnel, specific Air Force specialty (career) or skill distributions for those personnel, or maximum training resources available. As the system is developed, they might derive an optimum mix of these variables within these constraints.

In theory, human engineers function in the WSAP to convert these constraints into human engineering design criteria, and then to predict the MPT requirements consequences of the final design for the MPT planners. This function is, in essence, a cultural translation from the world of military infrastructure to that of drafting boards or Computer Aided Design (CAD), and back. The operative question for this report is, "How to effect this translation?"

Ref. Chapter 2, Design For Maintainability; What Military Standards Do & Don't Say, tools do not exist to enable this translation between engineering design and MPT planning. Without a credible connection between design and MPT requirements, levying MPT constraints and predicting MPT requirements are only ritualistic exercises until the operational test and evaluation of a prototype. By then, significant design changes have large cost and schedule repercussions; thus, they and so become infeasible.

In reality, MPT planning for new weapon systems is reactive to, rather than participatory with, design, and human engineering is without feedback concerning the human resources required to achieve satisfactory performance.

The fragmentation of human performance planning in the WSAP extends even further. At least six different Air Force (AF) communities must particpate:

- Human Factors Engineering. Human factors engineering is usually oriented toward operability rather than maintainability. Analysts are typically matrixed to System Program Offices (SPOs) from engineering staffs.

- Reliability and Maintainability (R&M). R&M is usually oriented toward reliability, rather than maintainability. Analysts are usually assigned under the Deputy Program Manager for Logistics (DPML) for each SPO.

- System Safety (S). S is usually oriented toward equipment failure and the designation of "human error" as a conclusive cause of safety incidents rather than a consequence of poor design. Analysts are generally assigned from safety rather than engineering staffs.

- Manpower (M). M is mostly performed by the operating MAJor COMmand's [MAJCOM's] manpower plans office. M is augmented by input from the Air Force Logistics Command (AFLC) manpower plans office for depot manning, from Air Training Command (ATC) manpower and technical-training personnel for training manning, and from the SPO for SPO manning. MAJCOM manpower planners typically do not have a complete picture of new technologies to be fielded on the emerging system; nor do they have a knowledge of human factors which might reduce manpower requirements.

- Personnel (P). P is managed by the AF Military Personnel Center (AFMPC), with coordination with the functional manager of each Air Force Specialty [AFS]; the MAJCOM manpower, personnel, training, logistics, and operations personnel; and the ATC technical and operator training offices of primary responsibility. Identifying the most correct AFS to staff the new system necessitates good human factors input about the skills, knowledges, and physical qualities of personnel which the new system will likely require. No formal mechanisms exist for this communication.

- Training (T). Formal maintenance training is conducted by ATC at technical training centers or field training detachments. Training that cannot be performed by ATC is assigned to On-The-Job Training (OJT) or specialized MAJCOM training. The 3306th Training Development Squadron assigns maintainers to test and evaluation aircraft to become familiar with maintenance actions and to conduct early phases of Instructional System Development. Often they identify maintainability problems and some are placed in service reports for correction. Unfortunately, redesign costs are often prohibitive this late in the acquisition phase.

Each community traditionally uses separate analysis tools and data bases. (Personnel and training use few, if any, tools.) Data bases supporting each domain are fragmented and cannot easily be translated into the data bases of another domain. For example, maintenance manpower uses the Maintenance Data Collection System, personnel and training use the occupational survey and Advanced Personnel Data Systems, safety uses lessons learned and MISHAP data bases, and human factors uses data bases like the Center for Anthropometric Research Data and predecessor SPO studies. Information gained in one domain is typically not passed along to others in any standard way.

The Armstrong Laboratory similarly fragments its development of new tools to serve its fragmented customer base. Different branches work in different disciplines. It is therefore not surprising that intradisciplinary analysis and data base/tool development is better understood and funded than interdisciplinary. The result is that the communities have no standard methods of communicating design-related data across domains.

In the authors' experience, this fragmentation has hurt all disciplines:

- Human Engineering has consistently suffered a lack of prioritization within acquisition because of its inability to express quantitatively the operational and life-cycle cost implications of its recommendations.

- System Safety is now being tasked to address why human error occurs in accident investigations. It lacks appropriate techniques.

- R&M is based on statistical predictions of failure and repair times which ignore the causal factors of human performance. Hence, it traditionally fails to address design for maintainability.

- Manpower estimates traditionally assume that new weapon system manning requirements will remain similar to the old requirements. Congress is now requesting guarantees of reductions of manpower requirements. Manpower planners lack techniques to predict requirements for significantly new designs with non-traditional manning.

- Personnel, responding to keep systems near 100 percent manning at the same time the overall force is reduced, wishes to utilize personnel across weapon systems in as few career fields as possible. This will ensure that individual career ladders will not be too small to manage effectively. Personnel also want AFS aptitude and technical specialization requirements to be reduced so that demographic trends and force reductions can be accommodated with the people likely to enter the military in fewer career fields. Unfortunately, personnel has no tools to determine what aptitude and technical specialization is required for proposed new weapon system designs.

- Training support and equipment are frequently acquired late due to cuts in training development budgets in favor of other program priorities. Training development might attain higher priority if its relationship to human performance, and hence mission performance, could be more explicitly demonstrated. In addition, training planning and development could be more efficient if career fields could be more finely tuned based on common skill and knowledge requirements. However, there is no standard way to determine skill and knowledge requirements from proposed new weapon system designs and communicate them to trainers.

The new Department of Defense Directive (DoDD), 5000.2, has recognized the need for the integration of human performance planning during the WSAP by including a separate section (equal with ILS) on Human-System Integration (HSI). HSI includes human engineering design, safety, manpower, personnel, and training. While this directive provides requisite policy to integrate human-performance-related disciplines, it recommends no tools to do so.

CAMT was conceived to be a pragmatic, credible, analysis procedure using an intrinsic data base to provide a cultural translation between engineering and logistics within HSI. As an effective interdisciplinary tool, it would inevitably contribute to intradisciplinary analyses, but it is not intended to supercede already existing tools and data bases. Rather, by more directly connecting subsystem design with Manpower, Personnel, Training, and Safety (MPT&S) consequences, we hope that individual MPT&S analysis tools will receive better source data, and human engineering evaluations will more directly reflect life-cycle resource requirements.

Associated Concepts

Comparative Anatomy

In biology, a comparative anatomy analyzes species into common body parts 1) to classify similar species into logically common ancestry, and 2) to compare/contrast the functioning of each part in its adaptation to various ecological niches.

In maintenance, a comparative anatomy would analyze tasks into common human performance parts 1) to classify similar tasks into logically common training sets and jobs, and 2) to compare/contrast the performance of each task part in its adaptation to the various weapon system designs.

Specifically, CAMT would:

- provide instant access to relevant maintainability design standards and lessons learned, as soon as the design is conceived;

- aid in predicting MPT&S requirements for specific design options;

- provide a more logical approach to maintenance training curricula than task-by-task teaching, i.e., teach common components to many tasks; and

- provide logical groupings of maintenance tasks into credible jobs and career fields as design becomes solidified.

The Scenario

The capabilities of CAMT are best understood through a realistic example. The following is a formal scenario that CAMT would specifically address.

A human engineering analyst on a design team is tasked to analyze one or more proposed subsystem designs and predict the maintenance MPT&S consequences of each. The analyst is specifically tasked to provide immediate design critiques from a user-interface perspective, estimate the consequences of each proposed design on MPT&S requirements, and then derive, in turn, the life-cycle cost implications of each.

The analyst has access to detailed design information and specifications for all subsystem components and their assemblies. The analyst also has a list of all required maintenance tasks as specified by the designer or the R&M engineer. Finally, the analyst has the CAMT data base at fingertip access and is familiar with its contents.

Note that this tasking is not for traditional MPT analysis; that is, to trade personnel skill requirements, training times, job/career field definition, and the number of people required in order to meet an established design's human performance requirements. Neither is this tasking for traditional human engineering analysis; that is, to compare a proposed design with human engineering specifications and guidance, then stop. Rather, it is to evaluate a proposed design using predicted "typical" MPT&S consequences. The emphasis is on design influence, not the derivation of the final MPT configuration. The tasking is thus to do HSI analysis, connecting the disciplines.

Traditional Discipline Boundaries

Successful integration of segregated dsciplines requires an understanding of their traditional domains.

- **Human Engineering** is the process of designing weapon systems, or of analyzing their designs, to be operator- and maintainer-friendly. It minimizes the difficulty of required human performance, in turn minimizing learning and performance time, propensity for human error, and the effects of stress from fatigue, battle, temperature, motion, altitude, noise, or collateral workload.

- **Maintainability**, applied to a weapon system, subsystem, or component, is the probability that it will be retained or restored to a given operational condition within a specified time period with minimum resources (people, equipment, budget). Designing for maintainability means designing for the shortest possible maintenance times and the largest probability of getting it right the first time. Some aspects of maintainability design do not directly relate to the maintainer: automated diagnostics, discard/replace options, functional location of test points, and sourcing of spare parts. However, most aspects do: accessibility, visibility, fail-safe orientation of replacement parts, minimum tool and crew requirements, potential safety hazards, etc. These aspects are part of human engineering.

- **System Safety** is the prediction and minimalization of the consequences of weapon system, subsystem, component, and user failures. The subset of system safety which deals with consequences of human failure is a part of human engineering.

Although human engineering, maintainability, and system safety all have infrastructure, life-cycle cost, and operational capability consequences, their primary influence is during weapon system design.

- The AF **Personnel** function manages the acquisition, classification, development, and nurturing of people to fill authorized positions AF-wide. The AF/Director of Personnel recruits, classifies by skill, assigns, tests, promotes, and otherwise manages career progression. It strives to ensure AF maintainers will be available in appropriate numbers, skills, and grades to fill present and future manpower authorizations. When tasks are reassigned between career fields (AFSs) or new ones are added because of the new weapon system, it coordinates the changes with the MAJCOM planning and logistics communities (MAJCOM/XPM and LG); the Air Staff functional managers; the Air Training Command Technical Training staff (ATC/TT) and technical training centers; and the AFMPC classification, assignment, and retention offices.

  AFMPC tries to resolve AFS specialty restructures to meet the needs of the specific weapon system while fitting in with the AFS structure of other weapon systems. The career field restructures must consider the long-term capability to recruit, train, assign, and retain career field members satisfactorily. The restructuring process could be faciliated by standard methods to group tasks into jobs, and jobs into career fields based on related skill, knowledge, and task performance requirements.

  The personnel function is also responsible for building the pipeline which takes people through recruiting or reclassification from other AFSs through initial or cross-training to assignment on the new weapon system. Personnel programs the pipeline based on the authorizations by AFS that the MAJCOM manpower office programs into the Unit Manning Document.

- Maintenance **Manpower** determines manpower requirements necessary for a specific weapon system to meet the prescribed sortie rate and mission type. For most aircraft maintenance positions, Manpower uses Logistics COmposite Model (LCOM) studies. These studies simulate the interaction of maintenance task assignment to AFS with predicted system performance paramenters and proposed organizational structure. Simulating the highest peacetime/wartime demand identifies the authorization levels at which manpower becomes the limiting factor in mission capability. These requirements, however, must be tempered by the end strength allowed by Congress. Authorizations are placed into the Command Manpower Data System, which produces the Unit Manning Document. In turn, this document provides the goal of AFMPC reclassification and assignment actions. The more accurately the emerging weapon system is depicted and the AFSs classified, the better the manpower predictions will be.

- Maintenance **Training** raises the skill and comprehension levels of available personnel to the proficiencies required by the manpower positions they are intended to fill. Technical training centers normally train general skill and comprehension requirements. Field training detachments then train weapon-system-specific skills and knowledge. Airmen continue training via OJT and correspondence courses. As their skills and knowledge increase they are upgraded progressively through "3-, 5-, and 7-skill levels". These correspond to apprentice, specialist, and journeyman levels of civilian job skills.

  During acquisition, training planning determines the best method of instruction for each anticipated task, then oversees procurement of the required materials, equipment, facilities, and support personnel. ATC handles formal training and the using MAJCOM handles OJT. Decisions about where and when to best teach a task could be improved if the specialties comprised related tasks, and the associated skill and comprehension requirements for each task were fully described.

MPT analyses constitute a more aggregate level of analysis than do safety, systems, or human engineering analyses. That is, while maintainability and potential safety hazards can be directly associated with the design of subsystems and components, MPT requirements are each the consequence of many subsystem designs. Thus, while small engineering changes in one subsystem often make significant changes in overall system maintainability (subsystem design effects on subsystem maintainability are easy to visualize and subsystem-to-weapon-system maintainability is a standard computation), their consequences for system MPT requirements are considerably less direct and intuitive to predict.

Additionally, a significant driver of MPT requirements is inertia in MPT practice. It may be too difficult to adjust the large, already existing human infrastructure of career fields, training courses, promotion tests, and maintainers in the pipeline to take full advantage of design-for-maintainability innovations. For example, although repairs would be quicker, overspecialized maintainers would be left without work. Or although fewer skills would be required, the training courses would still be the same length.

Consequently, traditional MPT planning has not focused on the suspectedly tenuous effects of detailed weapon system design. Now, however, Congress demands firm MPT requirements predictions for proposed new designs. Infrastructure inertia--using approximately the same number and types of maintainers for the new system as were used for the old--will no longer be tolerated. The design/MPT requirements link must be better understood.

CAMT is attempting to bridge some of the larger gaps between these human-related disciplines. "Comparing apples and oranges" will likely be difficult--and the underlying concepts just as difficult to understand. The greater risk, however, is associated with greater potential payoff.

An important final note about confusing terminology: by traditional AF usage (Air Force Regulation 800-15), "human factors engineering" refers to all of these disciplines (design for operability, design for maintainability, design for safety, biomedical engineering, manpower, personnel, and training); "human engineering," refers only to the design disciplines. The new DoDD 5000.2, however, uses "human factors engineering" to refer to what the AF traditionally called human engineering, and "human-system integration" tomean the traditional AF human factors engineering. Because of this ambiguity, this report henceforth will no longer use the term, "human factors engineering."

Hierarchy of Design Influence

To aid visualization of the interrelationships between disciplines, note Figure 1, the System Engineering Hierarchy of Design Influence. The referenced disciplines are ILS elements and subelements. Four levels of design influence are shown, from subsystem components at the micro level, to theater-wide warfighting capability and life-cycle costs at the macro level. The bottom two levels are actually the borders of a continuum of design influence which comprise traditional system engineering. Influence moves upward through the hierarchy, while mission requirements and constraints flow downward. Traversing levels of the heirarchy usually requires a translation of some variables, in turn requiring assumptions about the values of others.

To focus on the HSI disciplines, begin by noting that MPT requirements reside at Level Three, Infrastructure, along with the other ILS planning elements (e.g. support equipment, facilities, maintenance structure). They must derive solutions within the context of already existing administrative and support structures (e.g., AFSs, technical training centers, location of depots, support equipment already in the inventory, levels of maintenance). They often deal with multiple weapons (e.g., a squadron of aircraft) at many locations.

A weapon system's integrated logistics supportability directly influences its mission performance (via deployability, availability, and sustainability) and life-cycle costs at Level Four. A weapon system's integrated logistics

LEVELS OF DESIGN ANALYSIS

IV. Warfighting Requirements		***Theater Level***
* Mission Performance	* Life-Cycle Costs	
III. Integrated Logistics Support Requirements		***Infrastructure Level***
* Supply Support * Facilities * Manpower & Personnel	* Maintenance Planning * Support Equipment * Training Support & Eq.	* Computer Resources Support * Packaging/Handling/Transportation * Engineering Data/Config. Management
II. System Design Specification	*Primary Function* +	***Traditional Systems***
* System Safety * Hazardous Material * Interoperability/ Electromagnetic Compatibility	* Reliability * Maintainability * Survivability/Vulnerability * Corrosion Control	* Human Engineering * Energy Management * Non-destructive Inspection * Standardization/Parts Control
I. Component Design Specification	*Primary Function* +	***Engineering***
* System Safety * Hazardous Material	* Reliability * Maintainability	* Human Engineering * Energy Management

etc.

Figure 1. System Engineering Hierarchy of Design Influence (Logistics Perspective)

supportability is, in turn, directly influenced by the designed-in capabilities of individual weapons at Level Two, System Design Specification (e.g., range, payload, information throughput, survivability, reliability, maintainability, immunity to psychological stress and fatigue, environmental impact, etc.).

Individual weapon capabilities are, in turn, determined by (1) the designed-in capabilities of their individual components (e.g. reliability, maintainability, corrosion control, user interface, parts standardization, etc.) at the bottom of the hierarchy, and (2) the integration between individual components, assemblies, subsystems, and the weapon between Levels One and Two. During system engineering, trade-off analyses act horizontally in the hierarchy. They compare various apportionments of design requirements within a single discipline between components (assemblies, subsystems) and various specifications of single components between disciplines.

Human engineering design for operability, maintainability, and safety begins with weapon system components at the bottom of this hierarchy. Their consequences must undergo two major transformations to predict their MPT requirements on Level Three, and three to predict life-cycle costs at Level Four.

When surveying available acquisition tools, one finds a clustering at the top and bottom of the hierarchy. The engineering community excels at allocating design requirements from weapon to component and integrating performance capabilities from component to weapon. The logistics community excels at charting relationships between the functioning of each ILS element and life-cycle cost (and, to a lesser extent, overall system performance). Transformations between Levels Two and Three, however, are mostly uncharted.

Human Performance Prediction

What is the common ground of human engineering, safety, manpower, personnel, and training? They all exist to ensure human performance. Human operators or maintainers must be able to accomplish a certain interaction with the weapon system: first, to a certain level of accuracy; second, within a certain time period, and, third, with a controllable amount of collateral damage if they err. Could human performance provide a common, possibly quantitative, language to translate the effects of design between disciplines and traverse the hierarchy?

Figure 2 depicts a narrower system engineering hierarchy of design influence specifically addressing human performance. Traditional human engineering analyses proceed from the top downward; then study the effects of detailed system design on task steps. In contrast, logisticians study human performance on whole maintenance tasks to predict MPT requirements. Understanding design influence on the performance of whole tasks requires an understanding of design influence on the performance of each task step. There are approximately 10 to 40 task steps per task. Again, the transition between human engineering design effects on task step performance to the MPT requirements of whole tasks is mostly unchartered. Why?

Human performance is innately more fallible, variable between individuals, and changeable over time than other aspects of system performance. Therefore, it cannot be predicted by discrete mathematical formulae, as can reliability or corrosion control.

However, it can be estimated probabilistically based upon emprical data. To predict human performance on maintenance tasks for a proposed new design, one must first collect human performance data from similarly skilled people performing similar tasks (or portions of tasks) on similar designs under similar conditions. One may then compare each new design and its intended environment with this "baseline" to subjectively adjust the human performance information for design influence. One could similarly measure the MPT&S requirements for attaining this human performance on the baseline, then estimate the MPT&S consequences of each proposed design. This baseline information could be derived from (1) human engineering literature, (2) the field, or (3) parametric research studies.

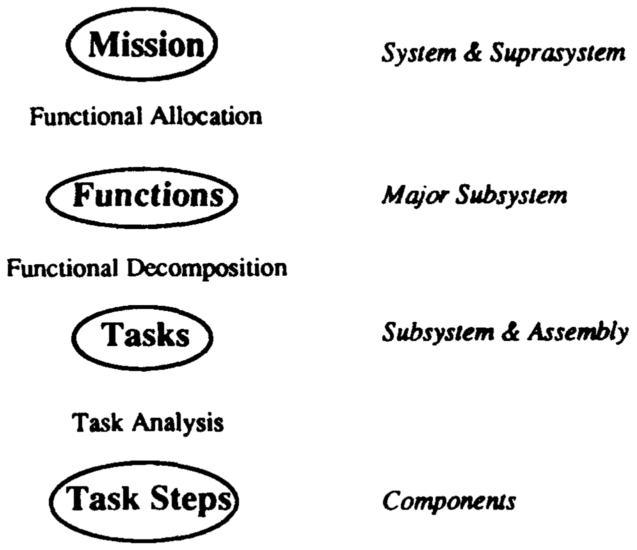

Figure 2. Human Performance Hierarchy

One could never remove all subjectivity from human performance estimation for as yet unrealized weapon systems; hence, automatic analysis programs could never replace the expert judgement of a senior design analyst. However, to improve the accuracy (and credibility) of human performance prediction, one could support the expert with comparative data that allow straightforward, well-scoped judgements. How well are such data currently being supplied?

Current Manpower/Personnel/Training Practice and Its Limitations

Current ILS analysis practice is to use field data to define a "baseline comparison system" (BCS)--a single composite of components from several similar, currently fielded systems. Subject-matter experts look at the new design, choose which components of older systems are most like those of the new one, collect relevant field data concerning logistics requirements on the baseline components, then extrapolate how the change in design will change these requirements in the new system. Maintenance task times, required skill levels, AFS assignments, and overall training costs are established this way, then input to other MPT analyses.

Under this approach the effects of design change on MPT requirements are difficult to estimate.

- **The BCS data**, once collected, **is highly specific to the weapon system** under study; more will have to be collected for each new weapon system--a nontrivial task.

- **The BCS data cover only one example** of an alternative design **for each subsystem or component**; they do not reveal how differing designs yield differing requirements.

- Since **human performance data are only collected from already deployed, similar systems**, the greater the change in technology between the new and baseline systems, the less relevant the baseline data will be. Perhaps more relevant baseline data would come from a similar maintenance task on a very different subsystem, but one which used the new technology. (For example, would maintenance on a digital radio be more like maintenance on an analog radio or more like that on a digital radar signal processor?)

- **The baseline data exist only at the whole-task level** (e.g., remove and replace, troubleshoot, calibrate) while design effects are evident only at the task-step level (align coupling, apply lubricant to gasket, attach probe). Collecting sufficient data to construct a baseline comparison system at the task-step level would be unwieldy. Therefore, each extrapolation of human performance from the baseline to the proposed system must include difficult-to-audit, difficult-to-verify assumptions abou the many design variables at the task-step level and their interactions.

Thus, the baseline-comparison-system approach, as currently practiced, requires large, complex extrapolations about subsystem design influence on human performance requirements from minimal baseline data. Could these **large extrapolations**, covering many implicit design variables, **be decomposed into more numerous, smaller extrapolations**, each with a more complete set of supporting data? If so, each extrapolation would be more straightforward and individual errors would have less effect on the overall analysis results.

The CAMT Concept

The CAMT approach proposes that human performance could be better estimated by using a level of analysis below that of whole tasks (which are too broadly defined to straightforwardly link to detailed design) and above that of task steps (which are too numerous and nuts-and-bolts oriented to straightforwardly link to skills or manpower slots). CAMT assumes one could, instead, define common segments of tasks, "task primitives," that would relate to both MPT requirements and human engineering design. The task primitives would serve as the foundation for a data base of typical MPT requirements, covering several representative subsystem designs for each primitive.

Such a data base would have three obvious advantages over current baseline comparison systems. First, subsystem and component design influence on MPT requirements would be easier to extrapolate for task segments than for whole tasks. Second, the commonality of the primitives to many tasks would allow a single data base to be relevant to many weapon systems or subsystems. Third, the commonality of primitives to many subsystems would allow several samples of design-versus-MPT requirements for each primitive in the data base. Multiple samples provide the analyst with the opportunity to note patterns in design consequences; these are useful for extrapolation to a new design.

The concept of an intermediate segment of human performance between a task and a task step is easy to postulate. Defining primitives for specific tasks in such a way to reap the above benefits, however, requires a more rigorous understanding of task primitive properties. A significant part of the CAMT concept development has thus been the evolution of a useful task primitive description.

The CAMT Task Primitive

Task primitives may be characterized as follows, progressing from general to specific attributes:

- A task primitive is a set of desired human behaviors that could logically be taught together.

- A task primitive is expressed as one or more action verbs plus one or more behavior object classes, with optional modifiers. (A "behavior object" is any tool, article, equipment component, or supplies with which the maintainer must come in contact while performing the task.)

- A task primitive is not a task step, although it conceivably could be identified from a single step. Most task primitives are based on several, usually non-consecutive steps which may be scattered throughout the task procedure. Nor is a task primitive a whole maintenance task--unless the task is very simple and its behavior objects can be generalized. Several task primitives comprise each maintenance task, and many maintenance tasks include the same task primitive.

(Examples of task primitives are (a) remove and install safety wire; (b) remove and replace oil drain plug; and (c) set and operate jack to raise/lower vehicle.)

- Each task imposes on the task primitive certain Design-Specific Characteristics and Constraints (DSC&Cs) for human performance. These are atypical human performance and resource requirements which result specifically from system design.

(Examples of DSC&Cs are (a) safety-wire accessibility; (b) the type of frame a jack must support (X, perimeter, unibody); or (c) drain-plug location.)

- Associated with each task primitive is a set of basic skills, practiced skills, and comprehension requirements.

    -- Basic skills are commonly required human performance capabilities, often learned prior to active duty.

(Examples include (a) using a screwdriver; (b) lifting heavy objects; or (c) reading technical orders. Attainment of basic skills may be reflected by achieving a minimum Armed Service Vocational Aptitude Battery (ASVAB) score.)

    -- Practiced skills are the unique proficiency requirements of each task primitive and must be trained.

(Examples include (a) tightening the oil drain plug to within a narrow range of torque values; or (b) ensuring that the jack contacts 4 balanced points on the vehicle frame.)

    -- Comprehension requirements involve theoretical understanding. They may either be common to many task primitives (such as understanding the basic principles of jet engine operation) or unique to one task primitive (such as understanding the principles of safety wiring).

- A useful set of task primitives must meet three criteria within their maintenance domain.

    -- Generality. Each task primitive contributes to many diverse tasks. Therefore, data indexed by it is useful in many contexts.

    -- Orthogonality. No two task primitives are highly correlated; there is never confusion about which of several task primitives apply when decomposing a task. This implies there is no ambiguity about action verbs or behavior objects.

    -- Completeness. Each maintenance task can be completely decomposed into task primitives with no task segments left over.

The initial identification of task primitives requires task analysis methodology. It entails a thorough examination of a task's steps, behavior objects, DSC&Cs for human performance, possible errors, and skill and comprehension requirements. However, as more tasks are examined within the maintenance domain, fewer new task primitives should be needed. Fairly soon, a newly examined task may consist entirely of previously identified task primitives. Only the DSC&Cs would be new.

When such a task is found, it means that training provided on the previously identified task primitives, if general enough, would be sufficient to establish proficiency on this task also. (This assumes DSC&Cs would be presented via job aids.) It also means that the MPT&S requirements of the previous tasks could be extrapolated to the new task, primitive by primitive. Finally, it means that the number of common primitives between two tasks could serve as a metric of task similarity to support AFS structuring; i.e., AFSs could be formed from task groupings that contain many common task primitives.

The CAMT Data Base

The purpose of the CAMT methodology is not to define another maintenance task taxonomy, but to serve as the foundation for a powerful, accessible data base to support concurrent engineering and integrated logistics support planning. As with current baseline comparison systems, CAMT data would be collected from field or laboratory experience with already existing designs; however, it would be collected for common task segments--rather than whole tasks--and sampled across several diverse designs--rather than just one. We assume that training on task primitives would also occur across several designs, rather than just a single weapon system, and would collect training-relevant data appropriately.

Data dictionaries would be built around 1) task primitives and 2) basic skill and comprehension requirements (which could apply to many task primitives). While the amount of data associated with each entry is large, it is readily collectable.

Associated with each basic skill and comprehension requirement would be:

- the notation of whether it could and should be trained (versus acquired through recruitment);
- the typical time to train, if appropriate;
- the typical method of training and associated costs; and
- the typical retention time when not used.

Associated with each task primitive would be:

- its definition;
- its associated basic skill, practiced skill, and comprehension requirements;

- general proficiency requirements (usually required accuracies) for its practiced skills;

- its potential human errors and their consequences over diverse design configurations;

- a sample of diverse relevant design configurations, along with the following information for each:

  -- its DSC&Cs,
  -- its typical time required for task primitive performance, and
  -- any design-specific proficiency requirements;

- especially relevant lessons learned and design guidelines, 1) indexed from human engineering standards and the AF lessons-learned data bank, and 2) derived from the DSC&Cs of other systems and their known human performance consequences; and

- the training required to achieve proficiency on its practiced skill requirements for several diverse relevant design configurations. Specifically:

  -- The typical time to train
  -- The typical method and cost of training
  -- The typical retention time for proficiency when not used.

The "typical method and cost of training" refers to the resources required to bring an entire class of students to proficiency, assuming they all meet minimum requirements. The "typical time to perform" refers to the time required by the slowest proficient (not marginal) maintainer. The "typical retention time" refers to the length of time proficiency requirements could be met without refresher training, when the task is not practiced.

Assuming task primitives could be culled from maintenance tasks and that the above data base could be populated, an analysis comparing new designs with older ones in terms of task primitives, rather than tasks, would offer many advantages.

- Since task primitives are common to many systems, a comparison system based on them would require only the CAMT data base. The attributes of any task within the maintenance domain could be assembled and extrapolated from those of its segments--the task primitives--for any design. This would eliminate the requirement to collect a new set of idiosynchratic baseline comparsion data for each new weapon system, saving analysis time and resources.

- Although there are essentially an infinite number of subsystems and components to be maintained (as in, "remove and replace box X," "test and verify card Y"), there are a finite number of behavior object classes (such as tubes, cables, couplings, cards, pumps, fasteners, fastener tools, measuring devices, inspection devices, cleaning agents, etc.). A data base for all task primitives within a maintenance domain, while large, should be considerably smaller than a data base covering entire maintenance tasks at the subsystem level (such as those maintained by the AF Occupational Measurement Squadron).

- Since task primitives would be common to many maintenance tasks, and therefore many designs, the task primitive data base could easily include multiple baselines. Human performance could be measured on at least three diverse designs; details of the designs themselves would be included. Admittedly, it would be highly unlikely for a design featuring substantially newer technology to resemble any of the design baselines. Nevertheless, the human engineering analyst could readily access examples of how differences in design correlate with differences in human performance.

- Since task primitives, by definition, are more specific than tasks, there would be fewer total influencing variables on human performance at the task primitive level. The effects of alternative design approaches on task primitive performance, as opposed to task performance, should be more direct and intuitive to estimate. (In corollary, data down to the level of individual task steps would be closely tied to component physical configuration, but would be intuitively distant from basic skills, training times, skill retention, manpower slots, etc.)

- Current human engineering design guidelines are contained in general standards. Theoretically, each design feature of each component should be checked with hundreds of pages of guidelines. This process is too tedius during iterative design and consequently doesn't occur until critical design review--if at all. The Air Force Lesson-Learned Data Base has a similar problem. Its index for maintainability lessons runs over 50 pages; no designer is likely to read all the lessons before tackling a project. Lessons-learned and design guidelines, however, could be specifically indexed to task primitives via their action verbs and behavior objects, such that as soon as an analyst calls out an primitive, s/he has ready access to human engineering criteria specific to the design in question.

- If task primitives are indeed defined to be general, orthogonal, and complete, they offer an efficient approach for organizing training. Technical schools could teach all the task primitives and underlying skills which comprise an AFS's maintenance tasks. Teaching them on multiple designs representative of the real world (e.g. on part task trainers) would produce versatile maintainers who would need only a well-written job guide to adapt to a new subsystem. The generality of the task primitive, as opposed to the equipment specificity of whole maintenance tasks, makes it an ideal foundation for such an approach.

Structuring the CAMT Data Base: An Example

Perhaps the best way to convey the concept of "task primitive" is by example. The discussion that follows describes methods for structuring a Task Primitive Dictionary and a Basic Skill and Comprehension Requirements Dictionary. The data are gathered through observation of task performance and through interviews with technicians thoroughly familiar with the subject tasks. Because of the similarity of task primitives across tasks within a system, the process gets easier as more tasks are analyzed. Once dictionaries for one system have been compiled, CAMT analysis for a similar system is much easier.

Removal and Replacement of the F-16 Jet Fuel Starter

The Jet Fuel Starter (JFS) is connected to the Accessory Drive Gearbox (ADG) by means of a V-band coupling (clamp). Before the coupling is removed, several tube nuts and electrical connectors must be disconnected. After the coupling is removed, the JFS is pulled back from the ADG and slowly lowered to the ground.

To begin removal, the technician first disconnects three tube nuts and removes the drain tube connected to the bottom of the JFS. One of these three tube nuts is connected to the purge tube, which runs between the drain tube and the top of the JFS. Next, the technician disconnects the upper tube nut of the purge tube. The remaining disconnections pertain to: the electrical connector (cannon plug), ignition cable connector, air tube nut, main fuel tube nut, and start fuel tube nut. (The air tube nut and the ignition cable connector have safety wire that must be removed.) When these disconnections have been accomplished, the JFS is free of the aircraft. All that remains is to loosen the V-band coupling and remove the unit.

To reinstall the JFS, the procedure is followed in reverse order. Any O-rings, seals, or gaskets that are damaged or deteriorated are replaced before JFS reinstallation. The tube nuts, ignition cable connector, and V-band coupling nut are tightened to specified torque values. The air tube nut and the ignition cable connector are safety wired.

To determine the task primitives for this task, the analyst will first list the types of behavior objects that the technician manipulates while performing the task, namely:

1. Compression fittings (tube nuts)

2. Cannon plug

3. Safety wire

4. V-band coupling

5. O-rings, seals, and gaskets

6. Torque wrenches

7. Crow's feet and extensions

8. Safety-wire pliers

9. JFS

10. Cannon-plug pliers

11. Open-end wrenches

Next, the analyst will consider combining some of the types of behavior objects to develop topics that would be taught together in training for this task. For example, one would not consider teaching about compression fittings (1) without also teaching the use of crow's feet (7) and open-end wrenches (11). Therefore, one should consider that numbers 7 and 11 are subsumed by number 1. One might also consider teaching the use of torque wrenches when teaching about compression fittings. However, torque wrenches may be used with other types of connectors and fasteners, and there is enough subject matter to be taught about the use of torque wrenches that a separate instructional segment on this topic would be justified.

Using similar reasoning, 10 should be combined with 2, and 8 should be combined with 3. Number 9 (JFS) is not a type of behavior object—it is too specific to the task. The analyst should consider: "to what class does it belong?" The JFS is a very heavy object. The job guide specifies that two persons should be used to lower it to the ground and raise it into position. Although one very fit and strong individual could conceivably handle it, this would not be a safe practice. There are many hints that can be conveyed about how heavy objects should be handled. Therefore, number 9should be changed to "manipulate heavy objects." The final list of task primitives for "remove and install the F-16 jet fuel starter" then becomes:

1. Disconnect and connect compression fittings.

2. Disconnect and connect cannon plugs.

3. Remove and install safety wire.

4. Remove and install V-band couplings.

5. Remove and install O-rings, seals, and gaskets.

6. Manipulate heavy objects.

7. Use torque wrench.

A technician who is competent in these task primitives is adequately prepared to remove and install the JFS, with the aid of job guides. Many of these same task primitives are present in other maintenance tasks. For example, the list of task primitives would be similar for the F-16 task: "Remove and install the engine-driven hydraulic pump."

Errors and Error Consequences

The next step is to list the errors associated with each task primitive and the consequences of those errors. The errors listed at this point are not system-specific. They are errors that would be expected if this same task primitive were observed in a different system. An example, for the first task primitive of the JFS task, is as follows.

1. Disconnect and connect compression fittings.

   1.1 Use of the wrong tools or overtorquing could result in rounding the nut.

   1.2 Incorrect use of crow's-foot extensions could make connection and disconnection difficult or impossible.

Design-Specific Characteristics and Constraints

DSC&Cs are task primitive factors that are unique to the task--that set apart the task primitive within this task from the same task primitive when it appears in another task (or even another system). For task primitives involving the disconnection of connectors or the removal of fasteners, such information as how many are disconnected (removed), and mechanical and visual access difficulties, should be recorded. For the first task primitive of the JFS task, an example of task-specific constraints is as follows.

1. Disconnect and connect compression fittings.

   1.1 Seven compression fittings need to be disconnected and connected.

   1.2 The upper purge tube nut and the air tube nut have difficult visual and mechanical access because of severely limited space above the JFS.

   1.3 Safety wiring of the air tube nut is accomplished in a severely limited space.

Design-specific characteristics of a task primitive include such data as acceptable voltages at test points, accuracy and precision requirements (in general terms), personnel and equipment safety hazards, and possible errors and their consequences. Examples of design-specific characteristics for the first task primitive of the JFS example are as follows.

1. Disconnect and connect compression fittings.

   1.1 All seven compression fittings must be torqued to specified values during installation. The torque values range between 75 and 370 inch-pounds.

1.2 Design-specific errors and their consequences are as follows:

1.2.1 Failure to disconnect one of the fittings during JFS removal could result in damage to the tube. Bent tubes will be hard to reattach. Kinked tubes will have to be replaced.

1.2.2 Failure to distinguish between the main fuel tube nut and the start fuel tube nut could result in improper torque.

1.2.3 Failure to distinguish between the drain tube nuts and purge tube nuts could result in improper torque.

1.2.4 If the upper purge tube nut is permitted to slip down the tube before the JFS is reinstalled, the nut must be located and brought to the top of the purge tube before it can be reconnected. This operation is difficult and time-consuming because the purge tube runs behind the JFS (where access is limited).

1.2.5 If any tubes are bent during JFS removal, the tube nut will not fit squarely on its threads, and it will be hard to start the nut.

1.2.6 The air tube runs from the inboard side of the JFS to the outboard. When disconnecting or connecting the air tube, some technicians tend to turn the nut in the wrong direction. Depending on how long it takes the technician to realize the error, the step can be very time-consuming.

1.2.7 Failure to use the two-wrench method when connecting or disconnecting some of the tube nuts can damage the tubes to which they are connected.

The design-specific errors listed above are the types of errors that experienced technicians should notice. They are essential for safety analysts and writers of technical orders; however, they are too specific to be of much use to MPT&S analysts. The CAMT analyst should examine these design-specific errors to determine whether some or all would be moved to the lists of errors associated with task primitives. The question to be answered is: Can a principle be derived from one or a group of these errors that, if conveyed through training, can reduce the frequency of this type of error? The design-specific errors listed above can all be translated into principles that need to be taught when presenting a course segment on the topic of compression fittings. The principles are as follows.

1.2.1 Before removing any component from which you have disconnected several compression fittings, review the job guide to ensure all necessary fittings have been disconnected.

1.2.2 Before torquing any compression fitting, review the job guide (especially the illustrations) to ensure the appropriate fitting and torque values have been identified.

1.2.3 Same as 1.2.2.

1.2.4 Before installing a new component (or reinstalling an old one), ensure all tube nuts are at the ends of their tubes.

1.2.5 When removing a component, avoid snagging (catching) a tube on some portion of the component. If a tube is bent, the nut will not fit squarely on its threads when reattaching the tube.

1.2.6 When the male union to which a compression fitting is attached projects <u>away</u> from the maintainer, there is a tendency for maintainers to turn the nut in the wrong direction when removing or connecting the tube nut. Identify all such cases at the outset, so time is not spent turning the nut in the wrong direction.

1.2.7 (This error is already stated in general terms. It can be moved without modification to the general task primitive errors.)

The next step for the CAMT analyst is to restate the design-specific errors in general terms and add these errors to those already on the task-primitive error list. For the first two design-specific errors, the revised error statements should begin with the words, "Failure to review the job guide...."

<u>Skill and Comprehension Requirements</u>

The skill and comprehension requirements are specific topics and behaviors that, when mastered, prepare technicians to perform task primitives. However, during MPT&S analysis, decisions may be made to fulfill these requirements through either selection, training, or performance aiding. Examples of skill and comprehension requirements for the JFS task are listed below.

1. Disconnect and connect compression fittings.

1.1 The two-wrench method; how and when to use it.

1.2 Principles of wrench use.

1.2.1 Choosing the type of wrench appropriate to the task (open-end, box, adjustable, crow's feet, tubing crowsfoot).

1.2.2 Choosing the right size wrench.

1.2.3 How to use an adjustable wrench.

1.2.4 Keeping the plane of the wrench perpendicular to the axis of the tube, nut, or bolt.

2. Disconnect and connect cannon plugs.

2.1 Recognition of the type of cannon plug and how to remove and attach it (screw, quick-disconnect, bayonet).

2.2 When and how to use cannon-plug pliers.

2.3 Types of keyways.

3. Remove and install safety wire.

3.1 Types and sizes of safety wire.

3.2 Safety-wiring methods (single-strand, double-strand).

3.3 Safety-wiring precautions.

4. Remove and install V-band coupling.

4.1 Types.

4.2 How they are constructed.

4.3 How they are loosened and tightened.

4.4 How to keep them out of the way when mating two components.

5. Remove and install O-rings, seals, and gaskets.

5.1 Their careful removal to preserve serviceability.

5.2 Their installation to provide a tight seal.

6. Manipulate heavy objects.

6.1 Principle of center of gravity.

6.2 Posture when lifting or lowering a heavy object.

6.3 Precautions to prevent injury.

7. Use torque wrench.

7.1 Types of torque wrenches.

7.2 How to set them.

7.3 Use of crowsfoot and extensions. The effect of extensions on torque measurements.

Once this structure is set, the Task Primitive Dictionary and the Basic Skill and Comprehension Requirements Dictionaries could be populated with data derived from interviews with technical school instructors and line-level supervisors of the responsible maintainers. Appropriate methodology will be addressed in a future study.

Human-Systems Integration Analysis with CAMT

Assuming a CAMT data base has been built, how will it support the scenario presented on page 1-5? The human engineering analyst is tasked to predict the MPT&S consequences for each of several proposed designs of a subsystem. These predictions will be used primarily for design evaluation and secondarily as inputs to more traditional MPT&S analyses. The analyst is given the CAD drawings of each design and the list of maintenance tasks associated with each. The analyst has the CAMT data base at fingertip access and should be familiar with it. "Subsystem" could refer to major subsystems, individual components, or any level of system design in between; "subsystem design" refers to how this level of system design is comprised of components from the next lower level.

How will the human engineering analyst generate a comparative anatomy of maintenance tasks, and what will s/he learn from it?

Referring to Figure 1, although a CAMT may traverse all four levels of the Hierarchy of Design Influence to some extent, its main value lies in traversing between Levels Two (System Design Specification) and Three (ILS Requirements). A CAMT will augment already existing tools when traversing between Levels One and Two, and between Levels Three and Four.

Figure 3 outlines a general maintenance anatomy through which the human engineering analyst will navigate when evaluating proposed subsystem designs. For each design option, the analyst will:

- break all required maintenance tasks into their constituent task primitives,

- look up the typical human performance and resource requirements for each constituent primitive,

- adjust these typical requirements to address the design under consideration (taking into account all DSC&Cs),

- aggregate these human performance and resource requirements back to task level, and

- aggregate these requirements across all relevant maintenance tasks to the subsystem level.

The subsystem totals serve as comparison criteria for competing design options.

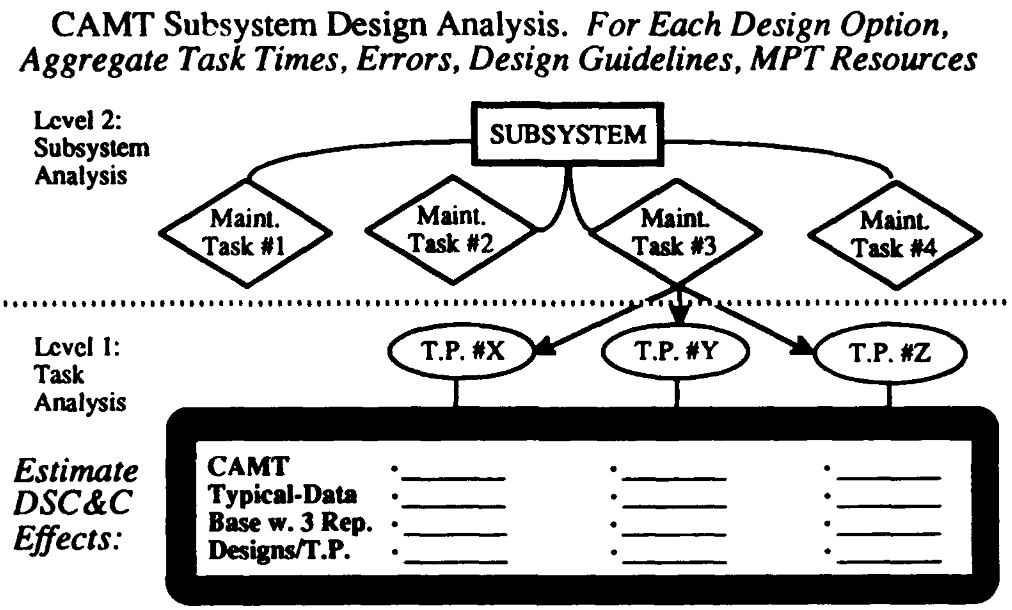

Figure 3. Overview: CAMT Analysis

(Although the top half of Figure 3 is reminiscent of traditional task analyses using single comparison baselines, the bottom half refers to accessing multiple baselines using the unique task primitive data base.)

The analyst begins with a subsystem design option to evaluate and a list of all maintenance tasks anticipated for this design. The specific steps follow in detail.

1. Maintenance Task Anatomy. Referring to the task primitive dictionary, decompose each task into its constituent primitives; then access their human performance and resource attributes in the CAMT data base. Via direct study of relevant CAD layouts, compare the proposed new design with the various baseline designs and their DSC&Cs in the task primitive dictionary. Identify any new DSC&Cs for human performance associated with the proposed design.

2. Basic Design Feedback. Via direct study of the relevant CAD layouts, evaluate the proposed design using the design criteria and lessons-learned associated with each relevant task primitive in the dictionary. For any discrepancies, recommend specific design modifications. (The task primitive dictionary information should be specific enough to allow this.)

3. Task-level Safety Data Generation. For each task primitive, itemize the potential errors and their consequences from the task primitive dictionary. Next, compare the relevant CAD layouts of the new design with the various baseline designs in the task primitive dictionary. Estimate any potential design-specific potential errors for the new design. Aggregate all potential errors to the task level.

4. Task-level Maintainability Analysis. First, via consultation with the designer, note any design-specific practiced-skill requirements for each task primitive (i.e., more/less stringent accuracy requirements or unique design-driven performance criteria). Then, by comparing the relevant CAD layouts of the new design with the various baseline designs in the dictionary, estimate the typical time for each task primitive's performance within the new design. Extrapolate this from the typical times to perform listed for the baseline designs, taking into consideration any DSC&Cs and any design-specific proficiency requirements noted above. Aggregate to task level.

5. Task-level Personnel Data Generation. Aggregate the basic ability requirements listed for each component task primitive to the task level.

6. Task-level Manpower Data Generation. For each task primitive, by compare the new design with the multiple baselines to estimate whether more than one person will ever be simultaneously required for successful performance. Note for redesign, if possible; otherwise aggregate such instances to the task level.

7. Task-level Training Data Generation. For each task primitive, (using the task primitive dictionary) itemize as training goals the comprehension requirements, practiced-skill requirements (general or design-specific, if appropriate), and any basic-skill requirements that must be trained. For each of these, list typical training methods, resources required, and times to train, as inputs to training planning and life-cycle cost estimates. Subjectively adjust the training times, if appropriate, to compensate for design-specific proficiency requirements (e.g., training to higher accuracy requires more practice). Aggregate to the task level, taking care to count each basic skill, practiced skill, and comprehension requirement only once per task.

8. Subsystem-level Safety Data Generation. Aggregate potential errors from all tasks to the subsystem level for use as input to system safety analyses.

9. Subsystem-level Maintainability Analysis. Sum typical maintainability times from serial tasks (e.g., remove-and-replace X, + troubleshoot X, + verify X) to derive typical times to repair for various faults called out in the Failure Modes and Effects Analysis. Compare these with maintainability allocations to determine the adequacy of the design.

10. Subsystem-level Personnel Data Generation. Aggregate all basic-skill requirements to the subsystem level to serve as a total of maintainer personnel qualifications for this specific design.

11. Subsystem-level Manpower Planning Strategy. Propose clusters of these maintenance tasks to be handled by single AFSs, using the following strategy. Aggregate task primitives across all subsystem tasks to form a subsystem listing. These can be compared with task primitive listings for other subsystems. Those subsystems whose tasks have the most task primitives in common may be assigned to a single maintenance specialty. Or, if they must be assigned to previously existing specialties, compare the task primitive listing for this subsystem with the aggregate requirements of existing specialties to choose a best match. Also, aggregate all occurences where more than one person must be present to accomplish a task primitive.

    Note: Instead of aggregating maintenance tasks to subsystem level, then grouping subsystems for assignment to a single specialty (based on commonality of task primtives), one could remain at the task level and cluster into specialties independent of subsystems. For example, the commonality of task primitves could conceivably lead us to the definition of more generic AFSs in cables, lubrication, electronic power supplies, signal processors, etc.

12. Proficiency Retention Analysis. Compare the expected time between task primitive performance with the expected retention time for task primitive performance. The expected time between performance is the inverse of the expected frequency of performance. The expected frequency of performance is, in turn, the sum of the expected frequencies of performance of all maintenance tasks which include the primitive.

    Hence, for each task primitive, itemize all maintenance tasks requiring its performance in the specialty as just defined. Add the frequencies of occurence for all these tasks, then compare (inversely) with the typical retention time for the task primitive's practiced skills. If a maintainer would perform the task primitive less frequently than required to maintain proficiency, it would be better to aggregate tasks differently for his/her specialty. Otherwise, refresher training must be provided, with its attendant increased resource requirements.

13. Subsystem-level Training Data Generation. Aggregate the comprehension requirements, practiced-skill requirements, basic skill requirements to be trained, accuracy requirements, typical methods of training, typical resources required, and typical times to train to the subsystem level. Eliminate redundancies.

    Note: It would be most efficient to structure training around task primitives rather than specific weapon systems; a new weapon system would thus only require new training on newly-defined task primitives or unusual DSC&Cs.

14. Job Aids. Once a design is finalized, collect all of its DSC&Cs, accuracy requirements, and potential errors, as well as the three-dimensional design information itself, as the foundation for specific on-the-job references, be they in the form of positional handbooks, technical orders, Integrated Maintenance Information System programs, etc.

What has the analyst learned upon completing these analyses? First, s/he has derived the following information.

1. A listing of all human engineering design criteria and lessons-learned relevant to this specific subsystem design and an assessment of how well this specific subsystem design heeds them

2. A detailed listing of all potential human performance errors associated with this specific subsystem design

3. Estimated performance times for every maintenance task or maintenance action (a group of sequential tasks) associated with this specific subsystem design

4. An aggregation of all basic-skill and comprehension requirements for human performance associated with this specific subsystem design's maintenance

5. An aggregation of all maintenance tasks where this subsystem design requires more than one maintainer (specified to the task primitive level)

6. Proposed optimum clusters of maintenance tasks for assignment to ideal AFSs, or proposed optimum clusters when forced to assign to traditional AFSs

7. A retention analysis of each proposed task cluster

8. A total of all practiced-skill, basic-skill, and comprehension requirements for human performance that must be trained for this specific subsystem design, and a reasonable estimate of the total cost and time for this training

9. A recommended technical school training approach for maximum training transferability: organize curricula around task primitives and train each on multiple design configurations

10. DSC&Cs and practiced skill requirements

Returning to the original scenario, information items 2, 3, 4, 5, and 6 can all be used as MPT&S-related design evaluation metrics: the less of each item, the better the design.

Additionally, this information provides a foundation for further HSI analyses.

- Result 1 serves as traditional human engineering analyses, but provides immediate, focused design feedback pertinent to each task primitive. It eliminates the tedious indiscriminant application of all human engineering standards and lessons-learned to all parts of the weapon system.

- Result 2 gives design-related input to traditional system-safety analyses.

- Result 3 gives design-related estimates of subsystem maintainability for all associated tasks.

- Result 4 can be compared to the anticipated demographics of recruits during personnel analyses. If the requirements are too high, the subsystem must be redesigned.

- Result 5 documents some design-related high-drivers of total manpower requirements.

- Results 6 and 7 provide a good strategy for assigning tasks to AF specialties in order to minimize training requirements.

- Results 3, 5, 6, and 7 provide design-related inputs to LCOM.

- Results 8 and 9 provide design-related input into Instructional Systems Development.

- Result 10 plus the actual CAD displays of the proposed design provide excellent content for job aids.

- Once CAMT analyses have been performed on subsystems from many weapon systems, their results could aid maintainer career planning (personnel management). To ensure optimum use of past experience on new assignments, a maintainer could be programmed into a series of assignments featuring most of the same task primitives but with substantially different DSC&Cs, or ones featuring a significant percentage of new task primitives each time while nevertheless keeping a majority of task primitives between succeeding assignments the same.

CAMT Applicability

When would a CAMT analysis be performed in the weapon system acquisition process? The purpose of the CAMT methodology is to integrate MPT&S considerations directly into the weapon system design process. It would thus be used throughout the system engineering process from the first appearance of three-dimensional configurations on a CAD system until actual prototypes are built for more direct maintainability testing.

Figure 4 summarizes what a CAMT system would and would not do.

CAMT is not:	CAMT is:
1. A CAD tool like Crew Chief, nor a base-level simulation like LCOM	1. A tool to *translate between* levels of design analysis, from design to MPT&S
2. An MPT&S tradeoff tool, reacting to a fixed design like Isoperformance	2. A *design analysis* tool, comparing "typical" MPT&S consequences of proposed design options
3. A modeling shell, performing calculations and logic on data to be input by the user like SUMMA	3. A *data base*, structured for easy access and utility across many applications at the user's workstation
4. Abilities based, focused primarily on maintainer characteristics like Fleishman	4. *Action* based, focused on task characteristics
5. A taxonomy, dealing with overall task traits for comparison	5. An *anatomy*, dealing with common task pieces for comparison

Figure 4. Comparative Anatomy of Maintenance Tasks
Focus

First Steps

Many feasibility issues arise. Our present effort had a very limited scope and addressed only the most fundamental issue: given a set of maintenance tasks on diverse systems, could we define a well-scoped set of task primitives which are general, orthogonal, and complete? We also performed a literature review for precedents for CAMT methodology.

SECTION II. FIELD STUDY

The purpose of this study was to test the feasibility of defining task primitives for three maintenance tasks and to determine the extent to which task primitives defined within one weapon system may be found in the same or similar tasks within other weapon systems. Three tasks within three weapon systems were examined. The tasks were removal and replacement of: the fuel pump, starter, and enginer turbine. The weapon systems were the J-57 engine of the KC-135, F-101 engine of the B-1B, and T-56 engine of the C-130.

Data Collection

A three-man team interviewed four Strategic Air Command (SAC) and two Military Airlift Command (MAC) engine-shop crew supervisors. For each task, the crew supervisors took the team members to the shop floor, showed them the connections and components involved, and described the task and any problems encountered in its accomplishment.

Next, the group went to a conference room to discuss each step of the task. If the data collection team had difficulty in visualizing any of the steps, they returned to the shop floor to watch the crew supervisors demonstrate the steps.

For each step, the following data were obtained:

- Step description
- Behavior objects (equipment, tools, and supplies with which technicians interact during the task)
- Constraints
- Possible errors

As the data were obtained, they were written on a whiteboard or blackboard, so that all participants could agree on the completeness and correctness of the data.

After obtaining these data for the first remove-and-replace task (the B-1B fuel pump), a discussion was conducted concerning the major curriculum items that would need to be covered in a basic course designed to prepare technicians to work in the engine shop. The following topics were mentioned by the crew supervisors.

- B-nuts (compression fittings)
    - -- Installing unions (jam nuts, thread protrusion)
    - -- Tube alignment (preventing cross-threading)
    - -- The two-wrench method (when, where, and how to use)
    - -- Torque wrench use (types, setting methods, calculating torque)
    - -- Safety wiring

- Electrical connectors
  - Types
  - Installation
  - Torquing
  - Safety wiring
- Common hardware
  - Nuts and bolts
  - Screws
  - Couplings and clamps
  - Pins
  - Seals
- Cleaning agents and lubricants
  - Safe use of
- Powered and non-powered Auxiliary Ground Equipment (AGE)
- Inspection procedures
  - How components look when they are unacceptably cracked, peeled, scored, etc.
- Common tools and measuring equipment

The crew supervisors were especially enthusiastic about using part-task trainers to teach such topics as how to remove, install, and torque nuts in situations where access is severely limited—and to provide practice in these operations. They also favored providing considerable part-task practice in safety wiring, extraction of panel screws, and removal and installation of gaskets and seals. One of the crew supervisors strongly favored teaching inspection criteria. He said that when he first came to the shop, he had no idea of what an unacceptable equipment item looked like—how bad was too bad.

Another discussion on training topics was conducted after data were gathered concerning the removal and installation of the starter on the KC-135. The following topics were mentioned.

- Lubrication
  - Types of lubrication
  - When not to use
    - Do not use oil where fuel is present
    - Do not use fuel where oil is present
    - Do not use fuel or oil for hydraulic or pneumatic connections
  - How to lube various types of components and connectors
  - What happens if you fail to lube

-- Toxicity of lubricants
-- How to dispose of used petroleum products

- Torquing

-- How to set the wrench
-- Consequences of over- or under-torquing
-- When recalibration of the torque wrench is necessary
-- False reading when the crow's foot contacts a component or line before specified torque is reached

- Safety wiring

-- Neutral pulls
-- Consequences of too much or not enough twist
-- Consequences of wrong type of safety wire
-- Do not cut pigtail on the diagonal

- Use of socket wrench

-- Getting the socket on straight (extensions)
-- Need for deep-well sockets
-- Knuckle protection
--- Use the heel of the hand
--- Anticipate a sudden break-loose
-- May have to remove another component to gain access

After data were gathered for all the SAC tasks (B-1B and KC-135), the study team and crew supervisors constructed a list of task primitives designed to cover all the tasks performed in the engine shop. At this point, all three tasks had been covered for two of the engines. The study team wrote a number of task primitives on the whiteboard, to start the process. Then, the crew supervisors added new task primitives and reviewed and corrected the ones the study team had proposed.

To illustrate the process, skill and comprehension requirements for three of the task primitives were identified by the crew supervisors.

When the same data were gathered for the three MAC tasks, no additional task primitives were required. The ones generated by the SAC tasks were adequate to cover completely all the steps followed by the MAC technicians. However, another discussion was conducted to elicit the crew supervisors' opinions concerning an optimal training curriculum for engine shop technicians. They produced the following training outline.

- Fundamentals of jet engine systems

-- Starter systems
-- Fuel distribution and injection systems
-- Pneumatic systems
-- Electrical systems (generation, ignition, sensor)

-- Hydraulic systems
-- Lubrication systems
-- Mechanical systems (gearbox)
-- Jet engines (how the systems work together)
-- Engine sections and what they do (compressor, turbine, diffuser, combustion chamber)

- General principles

  -- Safety
    --- Proximity standards (jet, propeller)
    --- Foreign object damage
    --- Wearing of jewelry
  -- Tool use
  -- Accessibility (including use of stands)
  -- Lubricants (including the importance of proper disposal)
  -- Technical orders (how to use)
  -- Forms and work unit codes

- Electrical systems

  -- Safety
  -- Types of connectors
  -- Reading schematics
  -- Continuity checks
  -- Possible errors

- Use of tools and measuring equipment

  -- Use/misuse
  -- Care of
  -- Accountability
  -- Special tools

- Fuel systems

  -- Safety (grounding, flammability, fuel handling)
  -- High/low pressure lines
  -- Contamination/filtering
  -- Color coding of lines

- Starting systems

  -- Types (electrical, pneumatic, cartridge, jet fuel)
  -- Safety (for each type)

- Ignition systems

  -- Safety (grounding)
  -- Types
  -- Source of ignition

- Lubrication systems

  -- Types of lubricants
  -- Safety
  -- Use (how to apply)
  -- Handling (disposal, storage, contamination)
  -- Lubricants for hot and cold sections

- Hydraulic systems

  -- Types
  -- Safety
  -- High and low pressure lines

Data Analysis

The first step in data analysis was to consolidate the raw data that were obtained concerning the steps, behavior objects, constraints, and errors for each task. Removal and installation of the components were combined, and the individual steps were collapsed is because within such groupings, task steps would likely require similar skills and comprehension and could logically be trained together. Appendix A presents the consolidated behavior objects, constraints, and errors for three remove-and-install tasks for three weapon systems.

Nearly all the constraints found in this investigation represented design problems that need to be solved on the current equipment and avoided in new engine designs. Some of the errors were task-specific, but many were perfectly correlated with the presence of certain behavior objects. For example, technicians must avoid prolonged physical contact with petroleum products. A possible error when using a torque wrench is to overtorque or undertorque the connector(s), both possibly causing the connector to loosen or come off. Similarly, standard errors may be associated with safety wire, gaskets, and electrical connectors. These standard errors and constraints can be straightforwardly converted to specific design criteria for systems incorporating these behavior objects.

The second step was to assign task primitives to the three tasks as performed on the three engines. Note that since task primitives are defined in relation to specific behavior objects, and since those behavior objects in turn can be associated with weapon system specific design criteria, human performance of task primitives can be directly associated with the weapon system design. This is a prime motivation for using task primitives as a foundation for human performance analysis of yet-to-be-realized designs. (It is anticipated that, similarly, typical comprehension and skill requirements, training requirements, and performance times may also be straightforwardly associated with each task primitive--both when these design criteria are met and when they are not. This would complete the connection of each proposed design approach with its representative MPT&S consequences. This assertion will be tested in a future CAMT feasibility study.)

Results

Figure 5 lists our first and second attempts at task primitive definition. Figures 6 lists associated skill and comprehension requirements for three of these task primitives. Figure 7 shows the task applicability of each task primitive.

The objective of this field study was to demonstrate an ability to define a set of task primitives that are general, orthogonal, and complete. It is clear from examining these results that these criteria were substantially (albeit imperfectly) met.

Generality

Generality is important to the feasibility of a CAMT data base. To keep the total number of task primitives in the data base well-scoped, each element must apply to many tasks on many weapon systems.

The task primitives first identified in this study are highly general; there was considerable overlap in the nine tasks under study (see Figure 7). Six of the task primitives appeared in all nine tasks. The task primitives first identified for the SAC tasks were deemed adequate for describing the MAC tasks. Of course, the tasks in this study were highly homogeneous. As other types of maintenance are investigated, new task primitives will have to be added. However, many of the previously identified task primitives will carry over to tasks such as those performed by electricians, pneudraulic technicians, egress technicians, environmental systems technicians, flightline crew chiefs, etc. Some will also be present in the tasks of electronic and avionics technicians.

Orthogonality

Orthogonality ensures there is never confusion about which of several task primitives to use when analyzing a segment of a maintenance task. The original list of task primitives constructed by the project team and crew supervisors did not perfectly meet the orthogonality criterion. Four task primitives were deleted. The 27 initially identified task primitives became 23, as shown in Figure 5.

Completeness

Completeness allows one to analyze any task into a set of task primitives with no segments left over. At first, this criterion seems trivial: one could just define new task primitives to cover any leftover segments. Accommodating both completeness and generality, however, may be more of an art. Every task primitive should to apply to as many different systems and system designs as possible. (If task primitives themselves were defined as design-specific, they would no longer support extrapolation to new designs. There would soon be as many primitives as designs; i.e. a limitless set.) Therefore, completeness really implies that each segment of each task studied should be common to at least one other maintenance task--an intriguing assumption.

DYESS AFB ENGINE MAINTENANCE TASK PRIMITIVE DEFINITION

First Draft: 27 primitives as listed on the left
Second Draft: 23 prmitives = the original 27 minus nos. 16, 18, 19, & 22, due to the rationale noted on the right

1. Remove and Install Safety Wire
2. Use Torque Wrenches
3. Remove and Install B-Nuts
4. Use Torque Multipliers
5. Apply Lubricants
6. Clean Components
7. Remove and Install Gaskets & Seals
8. Remove and Install Electrical Connectors
9. Remove and Install Common Fasteners
10. Use Hoists and Slings
11. Remove and Install Heavy Components
12. Remove and Install Clamps & Couplings
13. Use Transport Devices, Stands, & "Trucks"
14. Use Physical Measurement Devices (micrometers, vernier scales, etc.)
15. Inspect Components for Possible Reuse
16. ***Remove and Install Tubes and Lines*** ------------------------------------ *Covered by 3, 8, & 12*
17. Inspect and Diagnose Jet Engines
18. ***Remove and Install Hoses, Tubes, Ducts, Cables, and Wiring Harnesses*** ---------- *Covered by 3, 8, & 12*
19. ***Remove and Install Elbows and Unions*** -- *Combine with 3*
20. Dispose of Waste Fluids
21. Use Push-pull Fixtures (manual & hydraulic)
22. ***Remove and Install High-Pressure Hydraulic Tubes*** ------------------- *Covered by 3, 8, & 12*
23. Remove and Install Turbine and Compressor Buckets
24. Remove and Install Bearings and Carbon Seals
25. Use Heating/Cooling for Installation of Tight-fitting Parts
26. Repair Metal Surfaces
27. Use Common Hand Tools

Figure 5. First and Second Draft, Task Primitives: Three Maintenance Tasks on Three Aircraft Engines

Task Primitive: Install/Remove Common Fasteners

1. Types
   - A. Nuts & bolts
   - B. Screws
   - C. Hairpin cotters
   - D. Couplings/clamps
   - E. Ball-lock pins (pip pins)
   - F. Cotter pins, ordinary
   - G. Rivets (hollow, solid, pop)
   - H. Diaper pin cotters
   - I. C-rings
   - J. Roll pins

2. Installation & removal methods

3. How to avoid dissimilar metals

4. Application/Use
   - A. When to use - hot section, cold section
   - B. Thread pitch
   - C. Fixed/movable (a bolt with cotter pin is movable)
   - D. Reusable/not reusable
   - E. Conservation of precious metal

5. How to remove hard-to-remove fasteners
   - A. Normal methods
   - B. "Easy out"
   - C. Drilling
   - D. Use of penetrating oil

Task Primitive: Apply Lubricants

1. Types
   - A. Fuel
   - B. Oil
   - C. Grease
   - D. Jellies
   - E. Dry film
   - F. Anti-sieze

2. Hazards
   - A. Personnel
   - B. Equipment
   - C. Spills & cleanup

3. Application/Use
   - A. How to apply (hand, brush, gun, etc.)
   - B. How much to use
   - C. When
   - D. Where
   - E. What types not to use under certain conditions

4. Storage & disposal of lubricants

Task Primitive: Use Torque Wrench

1. Why torque wrenches are necessary

2. Types
   - A. Breakaway
   - B. Dial indicator
   - C. Ratchet

3. Methods of setting
   - A. Pull down handle
   - B. Locking collar
   - C. Screw

4. How to handle torque wrenches
   - A. How to read a calibration sticker
   - B. What to do if wrench is dropped
   - C. How to store wrench
   - D. How to zero out wrench

5. How to use torque wrenches
   - A. Can it be used in both directions?
   - B. How to read the dial type
   - C. How to calculate and set torque values when using crowsfoot, extensions, and adapters
   - D. How to identify when the breakaway type breaks away
   - E. False torques obtained when using crowsfoot

Figure 6. Comprehension and Skill Requirements for Three Task Primitives

Task Primitive #

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	17	20	21	23	24	25	26	27
C-130 F. Pump	x	x	x		x		x	x	x			x			x		x						x
C-130 Starter	x	x	x		x	x	x	x	x		x	x			x		x						x
C-130 Turbine	x	x			x		x	x	x	x			x	x	x		x						x
KC-135 F. Pump	x	x	x		x		x	x	x			x		x	x		x						x
KC-135 Starter	x	x			x		x	x	x		x	x			x		x						x
KC-135 Turbine		x			x				x	x			x		x		x						x
B-1B F. Pump	x	x	x		x		x	x	x				x		x		x						x
B-1B Starter	x	x	x		x		x	x	x		x	x			x		x						x
B-1B Turbine		x		x	x		x		x	x			x	x	x		x	x			x		x

Figure 7. Assignment of Task Primitives to Tasks

The 23 task primitives cover the training requirements for the nine tasks fairly completely. When the skill and knowledge requirements for all 23 tasks elements are identified, the result will be a nearly complete and comprehensive curriculum for engine shop incumbents. Figure 7 indicates some cause for concern, however, in that task primitives 4, 21, and 25 are each used only once. Could they be design-specific? No. Their behavior objects --torque multipliers, push-pull fixtures, and use of heating/cooling for installation of tight-fitting parts--indicate potentially broad usage on many other maintenance tasks.

To verify completeness, we compared the curricula that the SAC and MAC supervisors designed for engine shop technicians with the task primitives we identified together. We found several types of omissions in our task primitive list.

The first type consisted of curriculum topics that would have been represented if all engine shop tasks, not just a selected few, had been examined. These include: powered and non-powered AGE, extraction of panel screws, inspection for cracks/peeling/scores/etc., reading schematics, and continuity checks. These omissions are a result of the limited scope of our study.

The second type of omission consisted of very common comprehension requirements: how to use technical orders, how to fill out maintenance forms, hazards associated with volatile liquids, and hazards associated with electrical systems. These omissions would be contained in a Basic Skill and Comprehension Requirements Dictionary, which would complement the Task Primitive Dictionary. They are not likely to be design-sensitive, but would be important in predicting the overall training requirements of the system.

The third type of omission concerned the overall operation of the system being repaired: the sections of jet turbines and how they work together. There was some disagreement over exactly how much "theory" is required for a young two-striper, but there inevitably must be some. Again, the requirement to teach some general theory will not be design- sensitive. If needed for predicting training resources, however, it could be covered in the Basic Skills and Comprehension Requirements Dictionary.

The final type of omission consisted of requirements dealing with specific behavioral objects: fuel contamination, oil filtering, color coding of fuel lines, etc. These would be covered with more specific definitions of task primitives (see discussion below).

Within the limited scope of this initial feasibility study, we can declare our goals of defining task primitives that are general, orthogonal, and complete to be successful. This, however, is just one of several feasibility issues fundamental to CAMT design analysis.

Discussion

The primary use of task primitives is to bridge design features with their consequent MPT&S requirements. Defining task primitives too specifically—too close to the task-step level—risks losing their generality, requiring too many of them for a practical data base, and losing their connection to MPT&S requirements. Defining task primitives too broadly— too close to whole-task level--risks losing their ability to tie specific human performance to specific design configurations.

As discussed in the concept description, a CAMT analysis could have significant impact in several major areas: providing immediate design feedback, predicting MPT&S requirements once the design is set, and restructuring training more efficiently. When describing our study to the line chiefs, we stressed the latter, since this was a topic of constant concern for them. Manpower policy and acquisition problems were far less familiar.

Our first attempt to define task primitives, therefore, particularly stressed grouping skill and comprehension requirements which could be trained together for maximum efficiency. It gave little consideration to design utility. In retrospect, some primitives are defined too broadly for predicting the human performance consequences of design variations.

Consider:

6. Clean components
11. Remove and install heavy components
14. Use physical measuring devices
15. Inspect components for possible reuse
27. Use common hand tools

Could one find three representative design configurations for each which would scope most human performance consequences? Could one measure typical times to perform each? No, they each cover too many different cases.

These primitives will work, however, if we increase the specificity of their behavior objects. Referring to Figure 6, we could split "Use Torque Wrench" into two task primitives: one for breakaway wrenches and one for dial indicator wrenches. We could similarly define a separate task primitive for each type of common fastener: nuts and bolts, rivets, C-rings, etc. We could similarly define a separate task primitive for each type of lubricant: fuel, jellies, dry film, etc.

Task primitives defined at this level of specificity would retain a high degree of generality, orthogonality, and completeness. Yet, by addressing behavior objects of more specific design configuration, they could more specifically address the design of the behavior objects' immediate environment. Also, their human performance consequences could more easily be measured via parametric studies or in the field.

Several related task primitives (e.g., the two for torque wrenches) might indeed share basic skill and comprehension requirements, and could efficiently be trained together in a set. This is compatible with the CAMT concept as long as they remain orthogonal. Furthermore, some task primitives in Figure 5 might be better defined as basic skill and comprehension requirements themselves: remove and install heavy objects, and dispose of waste fluids. Such basic skill and comprehension requirements would only differ between design approaches if the differences in the approaches themselves were major (say, using different technologies). Usually, general basic skill and comprehension requirements will not have design consequences, but are important for scoping the overall skill and training requirements of (sub) system maintenance.

As we explore the building of the accompanying CAMT data base, we will continually fine-tune the task primitive definitions. Overall, our first attempt to define primitives of real-world maintenance tasks supports the plausibility, at least, of bridging design consequences with MPT&S requirements.

Future studies must address the following issues:

- Could a well-scoped set of general, orthogonal, and complete task primitives be further defined for electronic (versus mechanical) systems maintenance? For diagnostic/inspection (versus remove/replace) tasks?

- Could the Task Primitive Dictionary and Comprehension and Basic Skill Requirements Dictionary be populated with detailed, credible data in a relatively efficient manner? Could one arrive at a predicted cost per specified number of task primitives to build the data base in order to predict the cost of a complete CAMT system?

- Could CAMT analysis be demonstrated to perform credible design analysis relative to MPT&S requirements, given an appropriate sample problem?

SECTION III. ANNOTATED BIBLIOGRAPHY

Introduction

The Air Force tasked the contractor to conduct a literature review to obtain a theoretical foundation for task-primitive and skill definition. The specific purposes of the literature review were:

- To determine whether an "anatomic" approach similar to CAMT has been attempted before. If it has, to determine the reasons for its success or failure. If it hasn't, to highlight how other taxonomies compare with CAMT.

- To gain insight into methods for deriving general, orthogonal, and complete task primitives from a set of maintenance tasks.

- To gain insight into efficient means for populating the task primitive and skill-and-comprehension-requirements data bases, once the task primitives have been defined.

The Air Force performed a key-word search of the Defense Technical Information Center (DTIC) data base to obtain a listing of possibly related literature. The Air Force then used DTIC abstracts to select documents to be reviewed by the contractor with respect to the above objectives. Also included were some references personally accumulated by Capt Donald R. Loose. The contractor summarized each assigned document and noted relevance to CAMT. The contractor included negative findings; i.e., when relevant-sounding abstracts led to irrelevant documents. The findings follow.

Bibliography

Alley, W. E., Treat, B. R., and Black, D. E. (1988, September). Classification of Air Force Jobs into Aptitude Clusters (AFHRL-TR-88-14). Brooks AFB, TX: Air Force Human Resources Laboratory, Information Sciences Division. (AD A2066610)

The Air Force has four job clusters: Mechanical, Administrative, General, and Electronics. This study applied a new procedure for homogeneous clustering of regression equations in an Air Force ASVAB validity study involving 155,000 recruits in 211 technical training programs.

The present system of forming composites into the four job clusters listed above is remarkably robust, considering the myriad of changes that have taken place since the system was first established. A number of specialties were not well predicted--some because they have few cognitive demands, others because the demands they make are not sufficently represented in the current ASVAB. A recommendation was made to study these specialties further.

A recommendation was also made to consider forming a new cluster/composite. The tactical/strategic aircraft maintenance specialties included in this group seemed to reflect a "generalist" requirement--one that required abilities across the full domain of subtest measures.

While overall performance within each of the four job clusters correlates well with specific ASVAB profiles, it is not clear what proportion of the task primitives comprising each cluster would share this correlation. Until the effects of ASVAB scores on maintenance performance are studied on a primitive-by-primitive basis, they will be of no aid in a CAMT analysis.

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Driskill, W. E., Weissmuller, J. J., Hageman, D. C., and Barrett, L. E. (1989, August). Identification and Evaluation of Methods to Determine Ability Requirements for Air Force Occupational Specialties (AFHRL-TP-89-34). Brooks AFB, TX: Air Force Human Resources Laboratory, Manpower & Personnel Division.

This project reviewed the literature and identified 36 taxonomies that have been applied to the description of job and/or worker characteristics. The major orientation of this study was personnel selection. The authors were looking for job descriptive methods that can be used to derive aptitude and ability requirements. The following seven methods were chosen for further evaluation: Functional Job Analysis, Job Element Method, Position Analysis Questionnaire, Occupation Analysis Inventory, General Work Inventory, Threshold Traits Analysis System, and Ability Requirements Scales.

The authors concluded that the Ability Requirements Scales, developed by Fleishman and his coworkers, was the most appropriate of the existing methods for identifying the ability requirements of various Air Force occupational specialties. However, they found that no taxonomy adequately covered social and interpersonal communication abilities. They also felt that certain cognitive abilities that can be measured only through computer test administration have been omitted from existing taxonomies (e.g., the ability to visualize moving spatial objects in various configurations and at differing speeds).

They recommended that a new Air Force taxonomy of occupational abilities be developed. "The ability requirements for an occupational specialty would be determined through subject-matter-expert ratings of ability requirements for task statements categorized by the verbs in the task statements. This approach would enable generalization across occupational specialties. If this method were applied and ratings established for all relevant tasks, ability requirement profiles could be generated for any Air Force occupational specialty without the expense of subject-matter-expert conferences" (p. ii).

The latter notion of utilizing the results of previous analyses to save time and effort is also a feature of CAMT. Driskill et al. would use the ratings established for all relevant verbs to generate ability requirement profiles for new specialties. CAMT will use the data gathered from existing tasks in an existing weapon system to assist in analyzing the tasks in new weapon systems. Where the two systems have task primitives in common, the data from the older system will be transported to the new system.

* * *

Drury, C. G., Paramore, B., Van Cott, H. P., Grey, S. M., and Corlett, E. N. (1987). Task Analysis. In G. Salvendy (Ed.), Handbook of Human Factors (pp. 370-401). New York: John Wiley & Sons.

This chapter explores the origins and antecedents of task analysis and job analysis. These developments are described in some detail to show that there is no single method of task analysis applicable to all jobs. Finally, a task analysis of a large, complex system is presented in detail to illustrate both the techniques of task analysis and the methods of collecting the information required.

One of the methods described is the Position Analysis Questionnaire (PAQ) of E. J. McCormick. It has some characteristics in common with the techniques of the current CAMT project. The authors state, "The PAQ is clearly a different type of job analysis instrument from typical task analysis instruments in that it provides for the analysis of jobs in terms of basic human behaviors that cut across various types of jobs, rather than in terms of specific tasks that characterize the work activities of particular jobs or small groups of jobs" (p. 383). The CAMT technique also involves analyzing tasks to detect the presence of any of a previously compiled set of human behaviors (task primitives).

The PAQ asks 189 questions, with each question requiring a rating. Nearly all of the rating scales have five points. The questions are grouped into six major categories: information input, mediation processes, work output, interpersonal activities, work situation and job context, and miscellaneous aspects. The primary uses of the PAQ have been: personnel selection, personnel development and training, career ladder development, performance appraisal, and job evaluation (establishing rates of pay).

The task analysis methods reviewed in this chapter have the following characteristics in common with CAMT.

- They examine the activities of tasks.
- They identify their performance demands.
- They identify the skills and knowledge needed to perform them.
- They can be used to plan training curricula and course content.

CAMT and the typical method reviewed in this chapter differ in the following ways.

- CAMT stops short of describing tasks at the step level because the decisions that CAMT is designed to support (MPT&S decisions) do not require step-level description and analysis.

- CAMT is more efficient in that task primitives found in previously described tasks can be used to describe new tasks, as applicable.

* * *

Eggemeier, F. T., Fisk, A. D., Robbins, D., Lawless, M. T., and Spaeth, R. L. (1988, November). High Performance Skills Task Analysis Methodology: An Automatic Human Information Processing Theory Approach (AFHRL-TP-88-32). Brooks AFB, TX: Air Force Human Resources Laboratory, Logistics and Human Factors Division. (AD B128366)

The study described in this report attempted to determine whether part-task trainers aimed at the psychological facility of "automaticity" would be effective. "Automaticity" is a mode of information processing and resultant reaction that is largely automatic and seemingly effortless, but which handles complex and voluminous information. The focus of the study was on TAC and Air Force Space Command command and control tasks.

A distinction was made between two qualitatively different forms of information processing used by the command and control system operators: automatic and controlled. Automatic processing develops with extended practice under consistently mapped conditions for which there is a consistent relationship among task components. The following examples of automatic processing when driving a car were cited: applying the brake, interpreting traffic lights, and shifting gears. Controlled processing is typically associated either with novel tasks or variably mapped conditions for which task component relationships vary from situation to situation. Examples of controlled processing when driving a car are: interpreting a new road map, planning the route to be taken, and increasing the separation between vehicles to compensate for bad road conditions.

Observations and interviews with controllers enabled the study team to decompose controllers' tasks into automatic and controlled. The study concluded that much of an experienced controller's proficiency involves automatic processing of consistently mapped tasks, and that these tasks could be taught on specialized part-task trainers, thereby reducing training time and cost.

The relevant implication for the CAMT effort is that there exist tasks or portions of tasks that improve little with practice (where there are variably mapped conditions). If this is true, it may be because the necessary skills have already been acquired, not because the stimuli are variable. People who are learning to drive improve little in reading a road map only when they are already highly skilled in doing it. When they have a lot to learn (e.g., interpretation of map symbols), they improve with practice. CAMT notes a similar distinction in the definition of basic-skill versus practiced-skill requirements.

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Erickson, R. A. (1986, September). Measures of Effectiveness in Systems Analysis and Human Factors (NWC TP 6740). China Lake, CA: Naval Weapons Center. (AD A175353)

This report presents the thesis that the measures of effectiveness (MOEs) of any system are hierarchical in nature, ranging from the top-level MOE that indicates the worth of a system, through MOEs of mission capability, down to MOEs (or measures of performance) of individual tasks making up a mission. The top-level hierarchy includes factors such as cost, survivability, reliability, and capability. Guidelines are presented for developing the MOEs for a system's capability to accomplish a mission.

An MOE may be defined as a measure of the extent to which a system can be expected to complete its assigned mission within an established time frame under stated environmental conditions.

This study has little practical relevance to CAMT because its methodology operated at a higher level of system description than does CAMT's. Erickson focused on the identification of system objectives, the functions to be performed in attaining these objectives, and possible measures for evaluating their accomplishment. No attempt was made to describe or analyze the specific characteristics of tasks.

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Fleishman, E. A. and Quaintance, M. K. (1984). Taxonomies of Human Performance. Orlando, FL: Academic Press.

This book "describes and evaluates some taxonomic efforts to develop classificatory systems for describing human task performance. The objectives of such systems, their role in scientific development, and the practical implications are discussed" (p. 1).

Fleishman (1967) distinguishes abilities from skills. An ability refers to a more general capacity of the individual related to performance in a variety of human tasks. Fleishman (1967, p. 352) stated, "The fact that individuals who do well on task A also do well in tasks B and C but not in tasks D, E, and F indicates, inferentially, a common process involved in performing the first three tasks distinct from the processes involved in the latter three. To account for the observed consistencies, an ability is postulated." Thus, an ability is a general trait of the individual that has been inferred from certain response consistencies. Both learning and genetic components underlie ability development. In contrast, a skill is defined as the level of proficiency on a specific task or group of tasks. The development of a given skill or proficiency on a given task is predicated, in part, on the possession of relevant basic abilities (pp. 162-163).

Under the CAMT methodology being developed, skill will have a completely different definition. A skill will be a task requirement that demands practice for its acquisition by the task performer.

In defining ability factors, Fleishman and his colleagues are really linking together information about task characteristics with ability requirements. One may say that a person possesses the ability or, alternatively, that the task requires, involves, or elicits the use of the ability.

While Fleishman has tried many ways to classify human performance, the major one presented in this book is based on what human beings can do--on general abilities that have been defined through psychological studies. By contrast, the CAMT classificatory approach is based on what maintenance workers actually do--on task primitives derived from observation of work performance and interviews with workers.

A study described in detail is one by Theologus, Romashko, and Fleishman (1973). They developed an Ability Requirements Approach, which required judges to rate tasks on 37 ability dimensions, using a seven-point scale for each ability. The human abilities definitions are listed below (abbreviated from pp. 322-326).

1. Verbal Comprehension - Understanding words and words in context.

2. Verbal Expression - Communicating ideas or facts. Unrelated to the quality of the ideas.

3. Ideational Fluency - Producing ideas concerning a given topic. Number, not quality, of ideas.

4. Originality - Producing unusual, clever, creative responses. Degree of creativity, not number.

5. Memorization - Recalling accurately information presented during the task. Not recalling task procedures.

6. Problem Sensitivity - Recognizing the whole problem and all of its elements. Not reasoning.

7. Mathematical Reasoning - Understanding or structuring of math problems. Not manipulation of numbers.

8. Number Facility - Speed and accuracy of computation.

9. Deductive Reasoning - Applying general concepts or rules to specific ases. Involves the ability to synthesize disparate facts into general principles.

10. Inductive Reasoning - Finding general concepts or rules to explain observed relationships.

11. Information Ordering - Applying rules or objectives to arrange information into the most appropriate sequence.

12. Category Flexibility - Ability to produce alternative groupings or categorizations for a set of items.

13. Spatial Orientation - Maintaining one's orientation, in relation to objects in space or comprehending where objects in space are, in relation to observer's position.

14. Visualization - Manipulating or transforming visual images of spatial patterns. Visualizing how they would appear after specified changes.

15. Speed of Closure - Speed of organizing apparently disparate elements into a single meaningful pattern or configuration. All elements are in the same sensory modality.

16. Flexibility of Closure - Detecting a previously specified stimulus configuration among distracting stimuli. The relevant and distracting stimuli are in the same sense modality.

17. Selective Attention - Performing a task despite distractions from outside the task or monotonous conditions.

18. Time Sharing - Utilizing information coming from two or more channels of communication. May integrate the information and use it as a whole, or retain and use it separately.

19. Perceptual Speed - Speed of comparing sensory patterns to determine identity or degree of similarity. Patterns may be presented successively or simultaneously. The comparisons may be between remembered and presented patterns.

20. Static Strength - Applying continuous effort to lift, push, or pull a fairly immovable or heavy external object.

21. Explosive Strength - Expending a burst of muscular effort, as in jumping, sprinting, or throwing.

22. Dynamic Strength - Repeatedly or continuously supporting or moving the body's own weight by using the power of arm and trunk muscles.

23. Stamina - Maintaining physical activity over prolonged periods of time. The resistance of the cardiovascular system to breakdown.

24. Extent Flexibility - Extending, flexing, or stretching muscle groups. Degree of flexibility. Not repeated or speed flexing.

25. Dynamic Flexibility - Repeated trunk and/or limb flexing. Both speed and flexibility required. Ability of muscles to recover from flexing.

26. Gross Body Equilibrium - Balancing the body; not balancing objects.

27. Response Orientation - Speed of initiating appropriate response, given a stimulus, where two or more stimuli and two or more responses are possible. Not speed with which response is carried out.

28. Reaction Time - Speed of initiating a single motor response to a single stimulus.

29. Speed of Limb Movement - Speed of moving arms and legs. Not speed of initiation of movement. Not precision, accuracy, or coordination.

30. Wrist-Finger Speed - Speed of moving wrist and fingers. Same as 29 above.

31. Gross Body Coordination - Coordinating movements of trunk and limbs.

32. Multilimb Coordination - Coordinating the movement of two or more limbs, with the body at rest.

33. Finger Dexterity - Making skillful coordinated movements of fingers. Manipulation of objects may or may not be involved. Not manipulation of control mechanisms. Not speed of movement.

34. Manual Dexterity - Making skillful, coordinated movements of hands or hands and arm. May include manipulation of objects, but not manipulation of control mechanisms.

35. Arm-Hand Steadiness - Minimizing tremor and drift while maintaining a static arm position. Not manipulation of control mechanisms.

36. Rate Control - Making motor adjustments to intercept or follow a continuously moving stimulus whose speed and/or direction vary in an unpredictable fashion. Not where they are predictable.

37. Control Precision - Adjusting or positioning controls. Can be anticipatory motor movements in response to changes whose speed and direction are perfectly predictable.

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Hagman, J. D. (1980, May). <u>Effects of Training Task Repetition on Retention and Transfer of Maintenance Skill</u> (Research Report 1271). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences. (AD A101859)

This report describes a transfer-of-training study which examines the effects of practice with a 500A Sun Test Stand. It examined whether practice with testing of a 100-ampere alternator transferred to testing of a 60-ampere generator. The study had nothing to do with task taxonomies or task analysis.

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Hosek, J. R. and Peterson, C. E. (1988, November). <u>Developing an Initial Skill Training Database: Rationale and Content</u> (N-2675-FMP). Santa Monica, CA: The Rand Corporation. Prepared for The Office of the Assistant Secretary of Defense for Force Management and Personnel, Contract No. MDA903-85-C-0030. (AD A201689)

In 1983, the Secretary of Defense created the Training and Performance Data Center (TPDC). It includes information on training equipment and teaching aids such as simulators. Data on individual job performance and unit productivity were added as they became available. TPDC asked Rand Corporation to describe the kind of data that would be particularly useful for the initial skill training (IST) of individuals.

They concluded that data should be gathered on aspects of personnel training that relate to or affect military capability. Specifically, the IST data base files would contain data pertaining to: individuals, courses, occupation, units, and training resources. The data would be applied in the following five areas.

- Determining training loads for budgeting.
- Matching weapons system acquisition and training requirements.
- Managing skills shortages.
- Selecting personnel for military occupations.
- Determining the value of military training to the individual.

The report recommends that the TPDC gather course-descriptive data in its IST data base files (e.g., data on course content, skills taught, and prerequisites). If the course-content (curriculum) data were to include the time devoted to each course topic, these data could be used to flesh out the CAMT Basic Skill and Comprehension Requirements Dictionary. Unfortunately, it is not clear from the report that time-per-topic data is to be gathered. As presented, the most useful data for CAMT will be the skills taught in each course. These data can provide CAMT investigators leads for identifying sources they need.

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Kraiger, K. (1989, April). Generalizability Theory: An Assessment of its Relevance to the Air Force Job Performance Measurement Project (AFHRL-TP-87-70). Brooks AFB, TX: Air Force Human Resources Laboratory, Training Systems Division. (AD A207107)

This paper reviews the applicability of generalizability theory to the Air Force's Job Performance Measurement Project. The theory is illustrated by applying it to data collected from Air Force jet engine mechanics.

Generalizability theory is a method for estimating the dependability of scores over various conditions of measurement. In contrast to classical test theory (which permits the investigation of only one error source at a time), generalizability theory allows the researcher to simultaneously investigate multiple sources of error.

Classical test theory provides a single, true score but multiple estimates of true-score variance, depending on how error variance is defined.

Generalizability theory, on the other hand, explicitly recognizes the existence of multiple sources of error variance (such as items, test occasions, and raters) and provides methods for simultaneously estimating each.

Proficiency ratings were collected for 256 first-term jet engine mechanics. There were three facets of generalization: rating forms (4), specific items on each form (2 to 32), and rating sources (self, peer, and supervisor).

The question of interest was whether performance scores were generalizable (consistent) over different rating sources, forms, and items. The results indicated that scores were generalizable over both forms and items within forms. However, scores were not generalizable over rating sources. Sources tended to differentially rank ratees, depending on the specific form used. This finding suggested that it may be inappropriate to average scores over sources and that separate analyses for other facets should be conducted within rating sources.

The relationship of generalizability theory to construct validity and the logical requirements for performance ratings are discussed.

This paper extends generalizability theory--a tests and measurement theory--to job performance rating. It has no relevance to the CAMT methodology.

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Lintz, L. M., Loy, S. L., Brock, G. R., and Potempa, K. W. (1973, August). Predicting Maintenance Task Difficulty and Personnel Skill Requirements Based On Design Parameters of Avionics Subsystems (AFHRL-TR-72-75). Brooks AFB, TX: Air Force Human Resources Laboratory, Advanced Systems Division. (AD 768415)

The study had two primary goals:

- to investigate the relationships among equipment design characteristics, task difficulty, task performance time, and error probability; and

- to investigate the relationships between performance variables and personnel variables.

Organizational-level maintenance data were collected on 27 functional loops from 10 avionics systems. (A functional loop was defined as a network of circuits and equipment that performs a specific function.) Intermediate-level maintenance data were collected on 28 line replaceable units (LRUs) for the same 10 avionics systems.

Twenty-eight (29 for intermediate-level maintenance) equipment design characteristics were either measured objectively or rated by AF personnel. Data on 16 personnel characteristics were obtained.

Three maintenance tasks were identified for each functional loop and LRU--a functional checkout task, an easy task, and a difficult task. For each task, experienced AF maintenance supervisors estimated performance times and error probabilities for their high-skill and low-skill personnel. Supervisors also rated the difficulty of each task.

The design, personnel, performance, and difficulty variables were intercorrelated, and entered into regression and factor analyses. Equations were derived to predict performance and task difficulty from design characteristics, and to predict performance from personnel variables and task difficulty. Personnel factors and design factors were identified. Personnel profiles were developed for high- and low-skill groups. Plots of performance versus difficulty and task completion versus time were developed.

At the organizational level, six performance and personnel factors that were isolated were: Aptitude, Experience, Motivation, Breadth of Skills, Air Force Technical Training, and Time in Grade. Intermediate factors were: Length of Service, Aptitude, Electronics Aptitude, Avionics Experience, and Non-Air Force Technical Training.

Factor analysis of design variables indicated that factors associated with performance time and errors were: Checkout Complexity, Checkout Information, Length of Checkout, Accessibility, Equipment Complexity, and Test Equipment and Adjustments.

At organizational and intermediate levels, the low-skill groups required approximately twice the performance time of the high-skill groups, and had approximately six times the error probability. Aptitude was related to time and errors at the organizational level but not at the intermediate level, perhaps because the selection process had created greater homogeneity of aptitude for the intermediate personnel.

The relationships that were found are not unexpected. They reinforce the notions that:

- people with higher levels of aptitude, experience, and training tend to perform maintenance tasks more quickly and with fewer errors, according to maintenance supervisors; and

- equipment with lower levels of complexity, checkout complexity, and checkout length--and higher levels of checkout completeness and accessibility--is easier to maintain, as shown in experts' ratings.

The 2:1 variation in performance time and 5:1 variation in the number of errors between low-skilled and high-skilled maintainers supplies a useful rule for performing P, T, and S tradeoffs, but not for predicting design effects.

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Lobel, A. E. and Mulligan, J. F. (1980, January). Maintenance Task Identification and Analysis: Organizational and Intermediate Maintenance (AFHRL-TR-79-50). Brooks AFB, TX: Air Force Human Resources Laboratory, Advanced Systems Division. (AD A083685)

This report provides a draft specification that sets forth a process for obtaining the task-descriptive information to be incorporated into job-guide manuals and logic-tree troubleshooting aids. It speaks of "maintenance task analysis," which means "the analysis of the identified task to determine what the task consists of, what is needed to perform it, and how it should be performed" (p. 9).

The process includes the development of:

- a task identification matrix,
- a description of the intended user,
- listings of required support equipment and special tools,
- guidelines for determining the level of detail for writing job-guide manuals and logic-tree troubleshooting aids,
- an analysis of possible equipment faults and the resulting symptoms,
- effective step-by-step procedures for accomplishing each task, and
- action trees outlining a troubleshooting strategy for isolating each possible fault.

The methodology described in this specification addresses the development of performance aids after detailed design is accomplished. It is unrelated to CAMT.

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Perrin, B. M., Knight, J. R., Mitchell, J. L., Vaughan, D. S., and Yadrick, R. M. (1988, September). Training Decision System: Development of the Task Characteristic System (AFHRL-TR-88-15). Brooks AFB, TX: Air Force Human Resources Laboratory, Training Systems Division. (AD A199094)

The Training Decisions System (TDS) is a computer-assisted decision system that aids in planning the what, where, and when of training for Air Force career ladders. One of four basic subsystems of the TDS is the Task Characteristics System. The Task Characteristics System addresses what tasks need to be trained and where to conduct the training (training settings). It has two components:

- to construct Task Training Modules (TTMs) from occupational survey data; and

- to allocate the TTMs to the various training settings (such as formal training, OJT, etc.), and to determine the number of hours of training in each setting that is required, on average, to reach minimum performance standards for each TTM.

Both components rely heavily on the opinions of subject matter experts (SMEs). First, the tasks of an AFS were clustered statistically, using coperformance as the similarity measure. (Coperformance is defined as follows: given that an airman performs one task, coperformance is the probability that he or she performs other specific tasks.) Next, separate teams of SMEs were asked to cluster the tasks into groups that should be trained together. The SME teams then met to reconcile their differences and produce a final set of TTMs. Finally, for each TTM, the SMEs were asked to indicate the time they believed it would take to completely train the tasks to minimum standards, given a specific type of training. The types of training were: classroom instruction; correspondence courses; hands-on experience in small, supervised training groups; and hands-on experience on the job. If the tasks could not be completely trained using a particular type of training, the SMEs indicated the percentage of full training that can be provided and the time it would take to reach that level of proficiency.

After applying the methodology to four AFSs, the authors concluded that their survey procedure could yield adequately stable estimates of proficiency gains to be derived from hours of specified types of training.

If TTMs could be used as a basis for task primitive definition, the TDS data base could populate much of the CAMT data base. In CAMT, expert maintenance training personnel will be asked to estimate the likelihood of the errors that are listed and to rate the seriousness of their consequences, as well as to estimate the time to acquire specific skills and knowledge, and the expected frequency of refresher training.

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Primoff, E. S., and Eyde, L. D. (1988). Job Element Analysis. In S. Gael (Ed.), The Job Analysis Handbook for Business, Industry, and Government (Vol. 2). New York: John Wiley & Sons.

This chapter describes the Job Element Method (JEM) of job analysis, a technique for recruitment, selection, performance rating, promotion, and training design that the U.S. Office of Personnel Management has researched. Expert workers and their supervisors are asked to identify significant elements in a job and rate them. These may be intellectual elements, motor elements, or work habits. Elements are identified by asking what characteristics make a worker superior and what characteristics make for a weak worker. The elements are analyzed into subelements, or specific evidence of the presence or absence of an element. The subelements are rated to show the degree to which each subelement represents marginal behavior, superior behavior, behavior likely to cause trouble if not corrected, and behavior that is sufficiently prevalent among job applicants to be practical to consider. Primoff defines "job element" as a worker characteristic that influences success in a job. An element may be "a knowledge, such as knowledge of accounting principles; a skill, such as skill with woodworking tools; an ability, such as ability to manage a program; a willingness, such as willingness to do simple tasks repetitively; an interest, such as interest in learning new techniques; or a personal characteristic, such as reliability or dependability" (Primoff, 1975, p. 2).

The job elements of JEM are clearly at a higher (less detailed) level of description than the task primitives of CAMT. For example, where the JEM is satisfied with the job element, "skill with woodworking tools," CAMT would have a separate task primitive for each of the woodworking tools. Another difference between Primoff's "job element" and CAMT's "task primitive" is that the job element is an attribute of a worker, while a task primitive is an attribute of the task. The task primitive is a set of behaviors that would be taught together when the task is trained.

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Ramsey-Klee, D. M. (1979, December). Taxonomic Approaches to Enlisted Occupational Classification: Volumes I & II (NPRDC TR 80-7). San Diego: Navy Personnel Research and Development Center. (AD A078667 & AD A122028)

This study examines the taxonomic structure underlying the design of the Navy Occupational Task Analysis Program (NOTAP) task inventory booklets. It presents two alternative taxonomic procedures that will shorten task inventories and extend the usefulness of task analysis data.

A 55-item literature survey of taxonomic and classificatory methodology and systems is presented in Volume II and summarized in Volume I. Silverman's (1967) definition of the taxonomic process is as follows:

> A taxonomy involves the systematic differentiation, ordering, relating, and naming of type groups within a subject field.... The taxonomic process involves the following steps.
>
> 1. Collecting samples of phenomena.
> 2. Describing essential features or elements.
> 3. Comparing phenomena for similarities and differences.
> 4. Developing a set of principles governing the choice and relative importance of elements.
> 5. Grouping phenomena on the basis of essential elements into increasingly exclusive categories and naming the categories.
> 6. Developing keys and devices as a means of recognizing and identifying phenomena.

This study includes a statistical analysis of task-inventory response data for five Navy enlisted ratings and a content analysis of NOTAP task inventory booklets. Essentially, the study was aimed at reorganizing and shortening the NOTAP task inventory booklets used by the Navy in job analysis. The author recommended deleting job titles and reorganizing the task statements around a new set of categories developed during the project.

One of the statistics calculated was a frequency rank ordering of the equipment, tools, systems, and supplies that incumbents in each of the ratings use, operate, or repair. These lists contain items similar to the "behavior objects" CAMT analysts will consider when naming task primitives. Except for this similarity, the methods of the study and the taxonomic structure used to reorganize the task statements bear little resemblance to CAMT.

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Reigluth, C., Merrill, M. D., Branson, R. K., Begland, R., and Tarr, R. (1980, August). Extended Task Analysis Proceure (ETAP) User's Manual. Fort Monroe, VA: Training Developments Institute. (AD A098351)

This report was written as a reference document for the analyst who has already completed training in the use of Extended Task Analysis Procedure (ETAP). ETAP is a 12-step process designed to analyze (1) tasks that are primarily procedural in nature and (2) tasks in which the soldier has to adapt to current situations ("soft skill" tasks).

ETAP has three phases: process analysis, substep analysis, and knowledge analysis.

- Process Analysis. Preparing a flow chart that shows each of the task steps in proper sequence--identifying the decision steps and alternative sequences of steps (branches) which result from the decision.

- Substep Analysis. Applying process-analysis methodology to each step identified in the process analysis. This more detailed analysis is repeated until the resulting step is in terms of skills which the student has already acquired prior to training.

- Knowledge Analysis. Not all prerequisite skills or knowledge are best represented as procedures. Some involve knowing facts or pieces of data. Some are concepts and require the individual to identify objects or events in terms of their class membership. The process is to ask about each step or substep identified in phases 1 or 2: "What does the student need to know to perform this step?" If the answer is a concept, the same question is asked about that concept. Knowledge analysis is repeated until each identified concept is one already mastered by the student prior to instruction.

Some tasks require a different procedure each time they are accomplished because of constraints, conditions, and circumstances ("factors") that vary in each situation. The authors call such tasks "soft skills" or "transfer tasks." In such tasks, the task performers learn the principles underlying performance rather than a specific procedure. Each time the task is performed, the soldier derives a new procedure that is appropriate to the current set of circumstances. The training for such a task involves teaching the soldier (1) to recognize the various factors in a situation and (2) to derive procedures appropriate to each constellation of factors. ETAP has two analysis procedures to handle such tasks: factor-transfer analysis and principle-transfer analysis.

The methodology described in this manual results in a much more detailed description of tasks than CAMT provides for. It is truly "extended." For a procedural task, all the steps are listed--in correct procedural order. If any step is described at such a general level that the lowest-level entering soldier would not be able to understand what is to be done, they are broken down into substeps. For each "decision" step, the analyst identifies all factors that need to be considered when making this decision. This level of analysis is useful for the development of performance aids and preparation of training based on those performance aids. However, it is too detailed for making the types of decisions for which CAMT is designed (MPT&S decisions). Some methods for identifying knowledge and skill requirements could possibly be adapted for CAMT. However, their concept of "basic skills" includes "steps, facts, concepts, and principles" (see pp. 84 & 107); CAMT's does not.

The manual is well organized and probably quite helpful to the analyst. The total ETAP process is described and flow-charted. Checklists guide analysts through the process. For each portion of the process, there is a sample dialogue between an analyst and an SME. This dialogue shows the kinds of questions that need to be asked and the types of answers that can be expected. The analyst frequently recaps the SME's reply to test his/her understanding of the response.

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Root, R. T. (1957, March). Annotated Bibliography of Research Studies in Aviation Mechanical Maintenance. The George Washington University, Human Resources Research Office, Staff Memorandum. (AD F630578)

This memorandum describes reports concerned only with non-electronic maintenance. The first section (Mechanic Evaluation) describes and evaluates the graduates of ten mechanic courses given at Air Proving Grounds, Eglin Air Force Base, FL. The second section is intended to describe studies in task analysis, proficiency measurement, and criteria measurement. However, these studies are more similar to occupational measurement or job analysis than task analysis as we now think of it. They did not address skills, knowledges, or physical demands. The third section sets forth the "objective and approach" of seven projects being performed at the Maintenance Laboratory, Air Force Personnel and Training Research Center, Denver, CO. They deal with the design of job aids, training aids, and methods for identifying the skills, technical information, and concepts to be covered by job aids and training aids.

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Ruck, H. W. (1983, March). An Analysis of Selected Electronic Specialties for Skill/Knowledge Commonality. Brooks AFB, TX: Air Force Human Resources Laboratory.

This report describes a methodology for selecting electronic specialties for consolidation. The purpose of the consolidation is to effect more efficient and effective personnel management, personnel utilization, and technical training. The consolidation of specialties offers the following specific advantages:

- increased operational flexibility in utilizing personnel within field units;

- simpler assignments due to larger pools of eligible incumbents and fewer specialties;

- fewer initial-skills courses, resulting in simpler training management; and

- reduced manning, since specialists would have broader expertise and, therefore, fewer specialties (and specialists) would be involved in maintaining complex systems.

The Electronic Principles Inventory (EPI) was used to gather data about the underlying principles and knowledge required by journeymen in each specialty. The EPI asks 1257 questions that can be answered "yes" or "no." The questions pertain to what the technician does on the job and the electronic knowledge used to perform the job. The sample questions shown in the report ask whether the specialist works with various types of circuits.

The data were gathered from 12,295 job incumbents as a part of the Air Force Occupational Survey Program. The respondents were five-skill-level specialists. Twenty-three specialties and two career fields were involved. Seventeen specialties were part of the Communications-Electronics career field, and six were in the Wire-Communications career field.

Cluster analyses, correlational analyses, and analyses of variance were performed to determine which specialties within each of the two groups had the most similar skill/knowledge requirements. If the specialties were regrouped in accordance with the study recommendations, the original 23 specialties would be combined into 9 specialties. Two of the 23 specialties had such low requirements for electronic skill/knowledge that they were not recommended for consolidation with any other(s).

The EPI could be helpful for the CAMT analysis of electronic maintenance tasks. The EPI could help identify the "behavior objects" of each task. It asks questions like: Do you work with coupling devices in your present job? If yes, do you work with any of the following types of coupling circuits?

- Directly coupled circuits
- Capacitive-resistive coupled circuits
- Capacitive-inductive coupled circuits
- Transformer coupled circuits

Of course, the EPI covers only electronic principles.

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Shannon, R. H. and Carter, R. C. (1981, September). Task Analysis and the Ability Requirements of Tasks: Collected Papers (NBDL-81R009). New Orleans: Naval Biodynamics Laboratory. (AD A111181)

This is a collection of five papers presented at various professional meetings during 1980-1981. They discuss using task analysis to identify the abilities required for jobs as a first step in designing performance tests.

The first four papers describe task analytic methods used to classify recurring naval student-pilot flight errors during primary flight training in the T-34 aircraft. The fifth paper described the application of McCormick's PAQ to two Navy work stations that have similar tactical missions but different environments. The PAQ was applied to (1) the tactical tasks of the Combat Information Center of Navy ships and (2) the tasks of the Combat Information Control Officer aboard the E-2 aircraft.

The T-34 student-pilot studies used the following taxonomic outline:

A. Continuous Operations - Tasks involving multidirectional tracking responses.

1. Pitch Axis Control - Aircraft control in nose up/down axis.

   Maintain (a) altitude, (b) airspeed, (c) nose attitude, (d) stick pressure.

2. Roll Axis Control - Aircraft control in the wing up/down axis.

   Maintain (a) angle of break, (b) distance, (c) heading, (d) rate of descent, (e) stick pressure.

3. Yaw Axis Control - Aircraft control in the nose left/right axis.

   Maintain (a) balanced flight, (b) heading, (c) rudder pressure.

4. Thrust Axis Control - Aircraft control of forward movement.

   Maintain (a) rate of descent, (b) throttle pressure.

5. Brake Control - Aircraft control during ground operations by turning, stopping, or changing speed.

   Maintain (a) brake control.

B. Discrete Operations - Tasks involving individual distinct movements or mediating responses.

1. Procedural - Control of aircraft subsystems by not omitting, reordering, or improperly performing necessary sequential steps.

   Use (a) flaps, (b) landing gear, (c) fuel switches/lever, (d) canopy, (e) throttle, (f) prop, (g) battery/magnetos, (h) equipment, (i) checklists.

2. Anticipation/Planning - Tasks involving judgment, planning, and "being ahead" of the aircraft.

   Anticipate (a) aircraft, (b) position, (c) altitude, (d) airspeed; determine (e) wind direction, (f) landing site (g) location.

3. Communication - Tasks involving transfer of information from one source to another.

   Communicate (a) verbally, (b) visually.

4. Monitor - Searching and scanning inside/outside the cockpit for aircraft safety and maintenance of flight.

   Scan (a) for aircraft/obstructions, (b) temperature/pressure instruments.

Some of the definitions that were advanced are relevant to the present effort.

> Discrete operations are defined as individually distinct movements or mediating responses elicited by environmental cues. Continuous operations contain those tasks involving multidimensional tracking responses to either contact cues outside the cockpit or flight instrument cues within the cockpit. A task activity is a qualitative category whose main function involves either a sensory, cognition, motor, or coordinated perceptual-motor task... Finally, functional objectives are tasks having the same activity, goal orientation, sensory cues, and task primitives. For example, continuous pitch axis control contains the objectives to maintain altitude airspeed, nose attitude, and stick pressure (p. 1).

This study pertained to operator tasks and not maintenance, as does CAMT.

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Shriver, E. L., Fink, C. D., and Trexler, R. C. (1961, July). A Procedural Guide for Technical Implementation of the FORECAST Methods of Task and Skill Analysis. Washington, DC: Human Resources Research Office, Training Methods Division. (AD 262771)

Task FORECAST is said to be an attempt to provide methods for improving the accuracy of forecasting the skills and knowledges that electronic maintenance personnel must have to maintain their systems. The FORECAST approach is to have experts organize the system by developing schematic and block diagrams, and to determine the training demands from such information about the system. In actuality, FORECAST seems to be much more concerned with giving electronic technicians good performance aids (i.e., schematics) than with "forecasting" training needs. This report has no relevance to CAMT. The "Guide" fails to cover the topic of how to derive training needs. However, it is true that when the task is better defined, through good performance aids, it is easier to identify the information that must be covered in training. Applying the FORECAST approach would either reduce the length of electronics training or increase the effectiveness of the existing hours devoted to such training.

This manual is concerned primarily with troubleshooting.

> Troubleshooting is defined as "identifying the cause of an out-of-tolerance system output. In electronic equipment it is a process which involves the successive elimination, by interpretation of symptoms and measurements, of those parts of the system that are not causing the trouble. Using the electronics information at his disposal (e.g., signal flow), the repairman makes a series of deductions which progressively narrow the source of the malfunction to one or more out-of-tolerance parts (e.g., resistor, capacitor, cable). Replacement or adjustment of these parts constitutes repair of the system. (p. 5).

A repairman should have: (1) sufficient knowledge to compute the correct value at every possible check point in the system and, therefore, (2) the knowledge to determine the parts of the system that affect the values at every point. This means he needs two primary types of electronics knowledge: basic electronics and system-specific electronics. Basic electronics deals with general methods for computing circuit values. System-specific information is concerned with detailed circuit analyses which describe the effects produced by those circuits. In addition, repairmen are also provided with some information on the probabilities that various types of parts will malfunction. They use this knowledge to determine which parts in the system are within tolerance and which are out of tolerance for any particular malfunction. This paragraph is paraphrased from page 6 of the report. It is the closest the report comes to discussing the derivation of skill and comprehension requirements.

The manual devotes considerable attention to "blocking" an electronic system.

> A troubleshooting block consists of a fairly small group of parts which has one or more well-defined inputs and outputs. The relation of the block to its parts is such that, when all block inputs are good and one or more block outputs are bad, the malfunction(s) must, in all probability, be produced by one or more of the parts located within the block. Troubleshooting blocks are

conceptually similar to 'functional stages' in an electronic system but are different in that the relation of the block parts to the block outputs has been rigorously defined. In addition, a troubleshooting block may sometimes contain more than one stage" (p. 14). Taking measurements at block inputs and outputs enables the technician to rapidly narrow the source of the malfunction(s).

* * *

Siegel, A. I., Federman, P. J., and Welsand, E. H. (1980, December). Perceptual/Psychomotor Requirements Basic to Performance in 35 AF Specialties (AFHRL-TR-80-26). Brooks AFB, TX: Air Force Human Resources Laboratory, Manpower and Personnel Division. (AD A093981)

After reviewing the literature pertaining to taxonomies, measurement considerations, and job analyses, a taxonomy with 13 perceptual/psychomotor classes was devised based on Fleishman's work. "These final 13 abilities and their respective definitions are as follows:

1. Control Precision--the ability to perform rapid, precise, fine-controlled adjustments by either arm and hand movements or leg movements.

2. Manual Dexterity--the ability to perform skillful, well-directed arm and hand movements to manipulate either fairly large or fairly small objects.

3. Finger Dexterity--the ability to perform skillful manipulations of small objects with the fingers.

4. Multilimb Coordination--the ability to coordinate the movements of a number of limbs simultaneously, e.g., two hands, two feet, and hands and feet together.

5. Rate Control (Tracking)--the ability to perform continuous anticipatory motor adjustments relative to changes in speed and direction of a continuously moving object.

6. Visual Speed and Accuracy--the ability to perceive small details quickly and accurately.

7. Visual Memory--the ability to recall and state verbally or recall and reproduce through writing and drawings based on past visual experiences.

8. Position Memory--the ability to recall rapidly and accurately the position of objects from past experience.

9. Auditory Discrimination--the ability to discriminate and interpret sounds.

10. Auditory Memory--the ability to recognize and reproduce either verbally or in writing prior auditory experiences.

11. Clerical Perception--the ability to read or copy rapidly and accurately pertinent details in scales, graphs, or charts.

12. Perception of Size and Form--the ability to see slight differences in the size and shape of objects.

13. Depth Perception--the ability to determine the position of objects in space and to perceive in three dimensions" (pp. 26-29).

The methods were tested in two career fields and were applied in a large-scale data-acquisition effort which included 35 career fields. This work involved over 800 job incumbents at 10 Air Force bases. A factor analysis of the data indicated that the perceptual/psychomotor ability taxonomy can be described by three factors: visual, auditory, and manual factors.

The taxonomy developed by Siegel et al. is based on an ability-requirements approach to classification. CAMT task primitives will be based on behaviors instead of abilities. Siegel's taxonomy, however, may suggest basic-skill requirements, associated with specific primitives, which would be listed in the CAMT Task Primitive Dictionary.

* * *

Training Developments Institute (1979, August). Job and Task Analysis Handbook (TRADOC Pam No. 351-4). Fort Monroe, VA: Headquarters, United States Army Training and Doctrine Command.

This handbook describes how task analysis should be done in the Army. It includes a Task Analysis Worksheet (TRADOC Form 550). The major items of information to be gathered on this worksheet are the following:

1. Task title. - Begins with an action verb.

2. Task number.

3. Task conditions. - Tools, equipment, facilities, environment, etc.

4. Standard. - Procedures to be followed, time limit, errors permitted, production rate, tolerances, etc.

5. Job title. - Duty position.

6. Job aid recommended. - "Yes" or "no" and type.

7. Supervisory job? - "Yes" or "no."

8. Hazard potential. - During training and during the job performance.

9. Safety certification requirements. - Whether certification is required and the agency that issues it.

10. Equipment used to perform task.

11. Task selection data for training. - These data are derived from a questionnaire administered to job incumbents. One method for selecting training tasks involves asking the eight questions listed below about each task.

    Following the data categories is an indication of how the information is obtained from job incumbents.

    a) Percent performing. - "Do you perform this task?"

    b) Time between training and task performance. - 7-point scale. (1) Not yet performed; (2) more than 4 years; (3) 2 to 4 years; (4) 1 to 2 years; (5) 6 months to 1 year; (6) 3 to 6 months; (7) during first 3 months of assignment.

    c) Frequency of performance. - 4-point scale. (1) Never perform; (2) less than once per month; (3) at least monthly, but less than twice per week; (4) twice per week or more.

    d) Time spent performing task. - 7-point scale. 1 = very much below the average time spent on other tasks of the job; 7 = very much above the average time spent on other tasks of the job.

    e) Consequences of inadequate performance. - 7-point scale. 1 = negligible consequences; 7 = may result in mission failure, injury, death, or damage to important equipment.

    f) Probability of inadequate performance (in comparison with other tasks of the job). - 5-point scale. 1 = rarely if ever; 3 = about as often as other tasks; 5 = very often.

    g) Task delay tolerance. - 7-point scale. 1 = performance can be put off indefinitely; almost never urgent. 7 = must begin instantly.

    h) Task learning difficulty. - 7-point scale. From very easy (1) to very difficult (7).

12. References.

    a) Used in analysis.

    b) Required to accomplish task.

13. Current training materials.

14. Enabling skills and knowledges required.

    a) Baseline entry level. - Normal-repertoire behaviors required by the task.

    b) Skill hierarchy. - This is an inverted-tree diagram that shows the training objectives associated with the task and the enabling objectives for each higher-level objective. The skills and knowledges for each training objective are listed. The Handbook's guidance is probably not sufficient to enable novice analysts to construct such diagrams. It is somewhat confusing.

15. Performance elements/steps. - Each step is listed, and four items of information are recorded for each step.

    a) Step description.

    b) Cues. - What stimuli prompt initiation and termination of each step?

    c) Conditions. - Tools, test equipment, forms, references, etc.

    d) Standards. - How can step performance be evaluated?

    e) Skills/knowledge. - The skills are called "abilities" (e.g., "ability to read meters"). An example of knowledge is: "knowledge of polarity." They include normal-repertoire behaviors as well as behaviors to be included in training.

The methods described in this handbook are directly relevant to CAMT. They are similar to CAMT in that the lowest level of task analysis could be below the task level and above the step level. The handbook talks about "performance elements or steps necessary to perform the task." The analyst is permitted to stop short of the step level of description if using the step level would make the task description insignificant, vague, or trivial. Insignificant, vague, or trivial means a level at which all members of the target population can perform all of the steps without training. As an example of "element," the handbook breaks down the task of repair carburetor into three: clean internal parts, replace worn parts, and adjust mixture jets. CAMT would probably analyze this task into the same three task primitives.

Interestingly, the level of description this handbook tries to avoid is precisely the level of description the ETAP method of Reigluth et al. (1980) strives to achieve. ETAP carries its step and substep analysis to the level at which each step is described in terms of skills that the new job incumbent brings to the job. The Job and Task Analysis Handbook instructs the analyst to avoid this level of description, calling it "insignificant, vague, or trivial." CAMT avoids this very detailed level of description because it is not necessary for the MPT&S decisions that need to be made.

* * *

Wheaton, G. R., Rose, A. M., and Fingerman, P. W. (1975, September). Methods for Predicting Job-Ability Requirements IV: Task Characteristics, Ability Requirements, and Problem-Solving Strategies (R75-2). Washington, DC: American Institutes for Research. (AD A015719)

This report describes the fourth and final study in a program of research dealing with the relationships between the characteristics of human tasks and the abilities required for task performance. The previous studies found that complex changes in the ability requirements related to performance occurred in response to variations in task characteristics. In the fourth study, possible interactions among task variations, ability profiles, and subject strategies were examined within the context of the troubleshooting and problem-solving tasks previously studied. In general, knowledge of a subject's problem-solving strategy was useful in obtaining a clearer understanding of ability requirements under different conditions of task performance.

* * *

Wilson, M. G., Faucheux, G. N., Gray, J., Wilson, E. B., Lamb, T. A., and George, J. L. (1988, May). Optimizing Aircraft Maintenance Task/Specialty Allocations (AFHRL-TP-87-46). Brooks AFB, TX: Air Force Human Resources Laboratory, Logistics and Human Factors Division. (AD B122183)

This report describes Small Unit Maintenance Manpower Analysis (SUMMA), which uses task analysis and MPT data to decide how best to consolidate maintenance specialties to meet predetermined operational and maintenance scenarios. Specifically, the SUMMA project was designed to look at three questions: How can we disperse from larger fixed bases to smaller deployed sites? How many maintenance technicians will we need? Can we do the job without a large increase in the number of technicians?

The task analysis gathered the following information about each task.

From existing data sources (such as the technical orders, the Centralized Data System, and the Mission Essential Subsystem List), data were gathered on the following nine characteristics:

- task criticality,
- work unit code,
- mean time between occurrences,
- preconditions for task initiation,
- safety precautions,
- follow-on tasks,
- repeat discrepancies,
- type of maintenance (scheduled vs. unscheduled), and

- other tasks that cannot be performed simultaneously.

O-level SMEs were questioned regarding the following topics.

1. Level of Difficulty (under ideal conditions). Judged on a five-point adjectival scale.

2. Reason for Task Difficulty. Reason(s) for a task to be judged four or five on the difficulty scale.

3. How Skill Is Acquired. Major source from which respondents acquired proficiency in each task.

4. How Long This Skill Can Be Retained Without Practice. For each task, in months.

5. Number of Repetitions Required to Reach Proficiency. Number of repetitions before the respondent was certified as qualified.

6. Crew Size. Minimum number of persons who can safely perform the task.

7. AFSs That Normally Assist. If assistance is required, AFS and skill level.

8. Clock Time Required. Clock time to perform the task.

9. Probability of Successful Completion. Probability, in percent, that the task will be performed without error (including errors found through inspection and verification).

10. Suggested Alternate AFSs for Task Performance. Other AFSs that could easily be trained to perform the task (in order of desirability).

11. Clock Time Required (Alternate AFSs). For each alternate AFS, an estimate of the clock time required for performance.

12. Probability of Satisfactory Completion (Alternate AFSs). For each alternate AFS, an estimate of the probability of satisfactory task completion.

13. Electronics Knowledge/Ability Required. Knowledge and ability to make practical applications of electronics principles, concepts, and devices.

14. Mechanical Knowledge/Ability Required. Knowledge and ability to make practical applications of mechanical principles, concepts, and devices.

15. Fluids and Gases Knowledge/Ability Required. Knowledge and ability to make practical applications of the principles governing the behavior of fluids and gases.

16. Microprocessor and Computer Knowledge/Ability Required. Knowledge and ability to make practical applications of the principles and concepts involved in digital computing devices.

17. Metal Working Knowledge/Ability Required. Knowledge and ability to work with ferrous and non-ferrous metals in the repair, fabrication, and care of metal surfaces, objects, and devices.

18. Knowledge of Aircraft Structure/Systems Required. The extent to which general knowledge of aircraft structure and the locations of components, wires, tubing, etc. are required.

19. Muscular Effort. Strength and/or stamina required.

20. Adherence to Procedures. The degree to which fixed or set procedures are required.

21. Number of Procedural Steps. The number of individual steps or responses required.

22. Decision Making/Problem Solving. The extent to which decision making or problem solving is required, as opposed to set procedures.

23. Working with Hazardous Procedures/Materials. The extent to which hazardous procedures must be performed or hazardous materials must be dealt with.

24. Reading/Using Complex Instructions. The extent to which complex written instructions, diagrams, or other printed materials are required.

The following five questions were added for I-level SMEs.

1. After task proficiency is lost, how many uses are required to retrain? The number of times the test station must be used in performing a maintenance task to regain proficiency.

2. Can this skill be taught entirely on the job to someone from the Avionics (32XXX) career field? Could someone from the 32XXX career field (other than 326X4) learn this skill entirely by the OJT method; i.e., without the benefit of additional resident school training?

3. Could someone of average electronics aptitude (40-50) be trained to perform this task? Yes or no.

4. How frequently do you use the following test stations? The four AIS test stations are rated on the following scale: daily, weekly, monthly, every six months, or once a year.

5. If this test station is totally out of commission, are there alternate procedures that could be used to accomplish all or some of the test objectives? If "yes," list up to three alternate procedures and the testing objectives that are sacrificed by using each one.

This report discusses the MPT process, its decisions, and the job factors to be considered in making those decisions. It can help the development of CAMT by suggesting variables that can be used to populate the Task Primitive Data Base and the Basic Skill and Comprehension Requirements Data Base.

Summary of Literature Review

This review of civilian and military literature has revealed that the CAMT task primitive approach has not previously been used. None of the research examined had as its aim the construction of a data base which could be used repeatedly in making MPT&S decisions in the design of new weapon systems.

Several studies focused on what humans can do (abilities); CAMT focuses on what humans actually do--on "task primitives" derived from interviews with workers at the job site and observation of the task environment. These studies included: Fleishman and Quaintance, 1984; Driskill et al., 1989; Primoff, 1988; Siegel et al., 1980; and Wheaton et al., 1975. If these abilities proved to be prerequisites for task primitive performance, they could be listed as basic skill requirements in the Task Primitive Dictionary and documented during CAMT analysis as personnel requirements.

Only one of the documents analyzed jobs and tasks at the level of description we consider appropriate for facilitating weapon system design. This was the "Job and Task Analysis Handbook" written by the Army's Training Development Institute (1979). The most detailed level of task analysis was unquestionably used by Reigluth et al. (1980). Some of their methods for identifying comprehension and skill requirements might be adapted for use in CAMT.

The following reports provided clues as to how CAMT task primitives could be defined or how the CAMT data base might be populated.

- Driskill et al. propose a new AF taxonomy of occupational abilities that cross occupational AFSs. Common abilities requirements would be derived by analyzing a cluster of task statements containing the same verbs. If implemented, the choice of anchoring verbs might also serve to define task primitives. Relevant abilities requirements could then be transfered from the taxonomy into the CAMT Task Primitive Dictionary.

- Hosek et al. report that TPDC is attempting to catalogue the initial skill training of airmen. If TPDC collects course desciptive data and course content data--including the time spent on each topic--into an Initial Skill Training Data Base, this data could also serve to populate the CAMT Comprehension and Basic Skill Requirements Dictionary.

- Perrin et al. describe how the TDS is clustering maintenance tasks into Task Training Modules TTMs using co-performance criteria. If these TTMs could form a basis for task primitive definition, the TDS data base could populate much of the CAMT Task Primitive Dictionary.

- Ramsey-Klee's description of NOTAP referenced the program's frequency rank ordering of equipment, tools, systems, and supplies which incumbents in each of five Navy enlisted ratings use for operating or repairing weapon systems. This NOTAP list could suggest behavior objects of use for defining task primitives.

- Ruck's description of the EPI suggests that the electronic principles required for avionics maintenance tasks could be adopted as task primitives, or at least as a source of behavior objects. If so, the EPI data base could populate much of the CAMT Task Primitive Dictionary for these tasks.

- The Training Development Institute's approach to job and task analysis (TRADOC Pamphlet 351-4), if used, would provide much of the data needed in a CAMT Task Primitive Dictionary. Because they were published in 1979, there has been ample time to gain experience with these procedures. Their resultant data base might be accessible immediately. However, as yet we have no knowledge of how extensively these procedures have been used.

The next CAMT study will explore in greater depth those research programs at TPDC, the Armstrong Laboratory divisions at Brooks AFB, and the the Air Force Occupational Measurement Squadron.

SECTION IV. SUMMARY AND CONCLUSIONS

1. The CAMT concept responds to the need for a cultural translation between human engineering design for maintainability and its consequent influence on MPT&S requirements. Specificly, it addresses a system engineering scenario in which a human engineering analyst evaluates proposed subsystem design options in terms of their estimated typical MPT&S resource requirements for all related maintenance tasks. Additionally, CAMT provides immediate human engineering feedback to the subsystem designer from indexed standards and lessons learned, and design-related input to traditional MPT&S analyses once the design is chosen.

2. CAMT assumes that because MPT&S analyses typically address entire maintenance tasks and human engineering analyses typically address detailed task steps, analyses that link human engineering with MPT&S must address intermediate-sized portions of maintenance performance: task primitives. The concept of a task primitive was refined. Its use as the foundation for a new type of MPT&S data base was developed.

3. The CAMT data base would contain several designs associated with each common task primitive. Each design, in turn, would be associated with documented MPT&S consequences. CAMT would provide, in essence, multiple baselines with which to compare the proposed design, and the baselines' pieces could be reapplied to other tasks covering other subsystems. As with currently practiced comparability analyses, a CAMT would require expert judgement to extrapolate human performance from past to future designs. The CAMT data base, however, would significantly narrow the scope of individual judgements to enable more credible extrapolations, especially for radically new designs.

4. A review of civilian and military literature revealed that CAMT's task primitive approach has not previously been used. The methodology most closely approximating CAMT was found in the "Job and Task Analysis Handbook" written by the Army's Training Developments Institute (August 1979). The handbook addresses "performance elements or steps necessary to perform the task." The analyst is permitted to stop short of the step level of description if using the step level would make the task description insignificant, vague, or trivial. "Insignificant, vague or trivial" means a level at which all members of the target population can perform all of the steps without training. As an example of what is meant by "element," the handbook breaks down the repair carburetor task into three elements: clean internal parts, replace worn parts, and adjust mixture jets. CAMT would probably analyze this task into the same three task primitives. The literature review also revealed potential aids to defining task primitives and building the data base around them. We will explore these in future studies.

5. We conducted a field test of CAMT methodology addressing the feasibility of defining useful task primitives. We interviewed engine shop crew supervisors at Dyess AFB concerning three remove-and-install tasks as

performed on three weapon systems. The tasks involved the following engine components: starter, fuel pump, and turbine wheel assembly. In addition to identifying the task steps, behavior objects, constraints, and errors for each task, we asked the supervisors to construct curricula for training engine shop technicians. Finally, we proposed task primitives which we tested, as a set, against criteria of generality, orthogonality, and completeness.

6. Our proposed set of task primitives substantially met these criteria, although many primitives addressed too general a level of behavior object to readily link to design consequences.

   Generality. Task primitives defined for SAC tasks successfully applied to MAC tasks as well. Common primitives applied to equivalent tasks for an old jet engine (J-57), a newer jet engine (F-101), and an old turboprop engine (T-56). Common primitives also applied to various tasks on the same engine. Six task primitives appeared in all nine tasks.

   Orthogonality. The originally identified task primitives were not all orthogonal. We deleted four to create an orthogonal list.

   Completeness. To test completeness, we compared the training curricula constructed by the interviewees with the task primitive list. Training curricula topics not covered under the current task primitive list would have been in the associated Basic Skill and Comprehension Requirements Dictionary, or in task primitives defined to cover a larger task set than our limited sample.

7. A more narrowly scoped set of task primitives could be generated from our first proposed set by defining separate task primitives for more specific behavior object types. This set would inherit the first set's generality, orthogonality, and completeness; however, it would more readily allow the data base to store at least three representative samples of each behavior object which would typify many designs.

8. We recommend additional research to expand the CAMT feasibility exploration to a wider variety of tasks. To supplement the investigation of mechanical tasks, we should examine electronics tasks. To supplement the investigation of shop-level remove-and-replace tasks, we should examine flightline remove-and-replace, inspection/diagnostic, and bench-testing tasks. Subsequent research should expand the exploration of task primitive definition from primarily motor tasks to primarily perceptual and cognitive tasks.

9. Further studies must address the broader feasibility issues of efficient data base population and the reliability/utility of analysis results.

SECTION V. REFERENCES

Farina, A. J., Jr., and Wheaton, G. R. (1973). Development of a Taxonomy of Human Performance: The Task Characteristics Approach to Performance Prediction (Ms. No. 318). JSAS Catalog of Selected Documents in Psychology, 3, pp. 26-27.

Fleishman, E. A. (1967). Performance Assessment Based on an Empirically Derived Task Taxonomy. Human Factors, 9, pp. 349-366.

Loose, D. R. (1989). Chapter 2, Design for Maintainability Consequences. Design for Maintainability: What Military Standards Do and Don't Say, (AFHRL-TP-89-28), pp. 2-1 - 2-17.

Miller, R. B. (1967). Task Taxonomy: Science of Technology? In W. T. Singleton, R.S. Easterly, and D. C Whitfield (Eds.), The Human Operator in Complex Systems. London: Taylor & Francis.

Primoff, E.S. (1975). How to Prepare and Conduct Job Element Examinations (Tech. Study 75-1). Washington, D.C.: Government Printing Office.

Silverman, J. (1967, November). New Techniques in Task Analysis (SRM 68-12). San Diego: U.S. Naval Personnel Research Activity. (AD 663 135)

Theologus, G. C., Romashko, T., and Fleishman, E. A. (1973). Development of a Taxonomy of Human Performance: A Feasibility Study of Ability Dimensions for Classifying Human Tasks. JSAS Catalog of Selected Documents in Psychology, 3, pp. 25-26. (Ms. No.321)

APPENDIX A

BEHAVIOR OBJECTS, CONSTRAINTS, AND ERRORS

FOR THREE TASKS ON THREE AIRCRAFT

Fuel Pump Removal and Installation - T-56 Engine - C-130 Aircraft

Behavior Objects

High-pressure fuel filter hoses
Bolts
Washers
Fuel filter
Safety wire
Safety-wire pliers
1" open-end wrench
5/16" universal socket
1/4" speed handle
Rubber fuel container
Brackets
Cannon plugs
Safety wire
Duckbill pliers
Common slip-joint pliers
Filter
B-nuts
Jamnuts
3/8" box-end wrench
Diagonal pliers
7/16" socket
1/4" ratchet handle
Seals
Filter
Adel clamp
3/8" socket
9/16 open-end wrench
Fuel pump
Special fuel-pump-flange wrench (CX1416)
Gaskets
11/16" open-end wrench
1-1/8" socket
Torque wrench
Oil (MIL-L-6081, grade 1010)
Oil (MIL-L-23699)
Accessory-gearbox pad
Putty knife
Rags
3/8" crowsfoot
7/8" crowsfoot
1" crowsfoot
9/16" crowsfoot

Constraints

The top inboard fuel-pump-mounting nut is blocked by the pump, the accessory gear box, and the compressor housing. A special wrench must be used.

When the top inboard fuel-pump-mounting nut is being installed, it can be tightened with a special wrench but it cannot be torqued.

The engine must sometimes be turned by hand to align the splines.

Torquing the B-nuts of the fuel filter hoses is difficult due to the presence of other hoses and lines.

Errors

Failure to properly drain, contain, and dispose of residual fuel could cause injury to personnel and environmental damage.

Improper safety wiring could cause components to loosen.

Dropping a nut into the belly pan of the engine could cause foreign object damage.

Failure to install the bracket correctly could cause chafing.

Failure to remove all of the old gasket could cause a fuel leak.

Pinching the seal when installing the inlet line could cause a fuel leak.

Cross-threading or overtorquing B-nuts can shear the threads and cause a fuel leak.

Starter Removal and Installation - T-56 Engine - C-130 Aircraft

Behavior Objects

Starter
Pressure sensing line
Drain plug
Inlet air duct
Electrical leads
Engine gear case
Torque-meter-pickup harness
B-nuts
1/2" open-end wrench
Marman clamp
Clamp nut
7/16" deep-well socket
3/8" ratchet handle
Special EXQ-31 starter wrench (9/16"; 3/8" drive)
3/8" breaker bar
12" extension
9/16" locknuts and washers
Gasket
Putty knife
9/16" box-end wrench
Rubber oil container
Oil (MIL-L-23699)
Safety wire
Safety-wire pliers
Engine drive-gear female splines
Starter drive-shaft male splines
Rag
Stiff-bristle, nonmetallic brush
Cleaning solvent (P-D-680, Type II)
Paste lubricant (DoD-L-25681)
Torque wrench
1/2" crowsfoot
9/16" crowsfoot
Syringe

Constraints

The oil pump and the torque meter obstruct access to the locknuts that secure the starter to the engine drive case.

The generator blast tube duct and various electrical leads obstruct removal of the starter.

The weight of the starter necessitates two technicians for removal and installation.

Errors

Nuts or washers dropped into the engine compartment could cause Foreign Object Damage (FOD).

Dropping the starter could injure personnel or damage equipment.

Failure to remove all of the gasket could result in an oil leak after installation.

Prolonged physical contact with oil could be harmful to personnel.

Failure to clean and lubricate splines during installation could cause an oil leak, heat build-up, and seizing.

Undertorquing could result in leaks.

Overtorquing or cross-threading could shear off threads.

Overfilling the oil could cause the seal to fail and leak.

Underfilling the oil could cause the starter to seize.

Improper safety wiring could cause a fastener to loosen.

Compressor Turbine Removal and Installation - T-56 Engine - C-130 Aircraft

Behavior Objects

Self-locking nut
Safety wire
Diagonal cutting pliers
Inner rear exhaust cone
Special cone puller (No. 6795867)
3/8" socket
3/8" ratchet handle
Thermal insulation blanket
Bolts
Safety-wire pliers
5/16" socket
Speed handle
Rubber mallet
Metallic O-ring seal
Gasket
Engine oil
Lockring
Tie bolt
Tie-bolt locknut
Special tie-bolt locknut wrench (No. 6796530)
Special Y-bar support (No. 6796382)
Rear scavenge pump drive coupling
Tie-bolt lockpin
Special turbine-to-compressor tie-bolt spanner wrench (No. 6796533)
Heavy mallet
Fire seal collar access doors
Common screwdriver
Cam-lock screws
Igniter plugs
Liner supports
1/4" ratchet handle
12" extension
Thermocouple wiring harness
1/4" speed handle
3/8" box-end wrench
Nuts
3/4" box-end wrench
Lifting adapter
Hoist
Special turbine coupling shaft holding fixture (No. 6796621)
Turbine unit
Turbine transport stand
3/8" box-end crowsfoot
Dial indicator (total-travel gauge)
Axial-clearance gauge adapter
Offset screwdriver, common

7/16" box-end wrench
Pencil and paper
Special turbine rotor axial movement positioning wrench
Torque wrench
Breaker bar
Heat-treated safety wire

Constraints

The safety wire holding the inner-rear-exhaust-cone retaining nut is difficult to remove completely because it is in a figure-eight configuration and passes twice through the hole in the stud.

High torque is required to break loose the tie-bolt retaining locknut. The special wrench used is a special socket attached to a breaker bar.

The four top bolts of the combustion outer casing-to-turbine inlet case splitline are difficult to break loose.

When positioning the turbine unit for installation, it is difficult to obtain the correct alignment to engage the splines on the compressor rotor shaft.

The securing screw for the gauge adapter is located inside the support case. Therefore, an offset screwdriver must be used when attaching the dial indicator.

Installation of the turbine rear scavenge pump can be difficult because access to some of the bolts is blocked by the pump.

After the nut that secures the exhaust cone has been installed, it must be secured with heat-resistant safety wire wrapped in a figure-eight pattern.

Errors

Prolonged physical contact with oil is harmful to personnel.

If not done carefully, breaking loose the tie-bolt retaining locknut could endanger personnel or damage engine components and tools.

The four top bolts of the combustion outer casing-to-turbine inlet case splitline could be rounded off during their removal or installation. Their nuts could also be rounded off.

If the oil tubes are bent when inserting the turbine unit, they will hinder insertion or have to be replaced.

Failure to measure the front-to-back travel of the turbine rotor will necessitate removal and reinstallation.

Improper torquing techniques could cause fasteners to loosen and damage the engine.

Failure to zero the dial indicator will result in incorrect measurement.

Improper safety-wiring techniques could cause fasteners to loosen and damage the engine.

Overtorquing the thermocouple nuts could damage the thermocouple.

Fuel Pump Removal and Installation - J-57 Engine - KC-135 Aircraft

Behavior Objects

Fuel inlet tube
Waste fuel container
Fuel supply line
Safety wire
Safety wire pliers
JP-4 fuel
Flange nuts
Flange bolts
Washers
1-7/8" open-end wrench
7/16" universal socket
6" extension
12" extension
1/4" ratchet handle
O-ring seals
Double cable clamp; bolt and nut
Fuel pump discharge line
Water injection switch lead
3/8" deep-well socket
3/8" open-end wrench
Seals
Adel clamps; bolts and nuts
Ford wrench
Bypass-to-pump inlet line
1/2" deep-well socket
1/2" box-end wrench
Return-to-first-stage pump inlet line
7/8" open-end wrench
Seal-drain line
5/8" open-end wrench
Water-sensing tube
Accessory-drive suction line
Wire bundle
B-nuts
9/16" open-end wrench
Temperature-sensing line
Water-sensing tube
Valve
5/16" shallow socket
Fiber drift (rod)
Mallet
Locking ring; bolt
Fuel pump
Adapter; bolts
3/8" ratchet handle
2" extension

9/16" deep-well socket
Gasket
O-ring seals
Elbows; jam nuts
Adapter plate and bracket
Petrolatum
Oil (MIL-L-7808)
Acid brush
Torque wrenches
Rag
Go/no-go wear gauge (PWA 17286)
Plastilube Moly No. 3 grease
Feeler gauge
Flashlight
Mirror
11/16" crowsfoot
7/16" crowsfoot
9/16" crowsfoot
5/8" crowsfoot
7/16" torque adapter
5/16" universal socket
3/8" universal socket
1 7/8" crowsfoot
Grease (MIL-G-21164)

Constraints

When disconnecting the fuel supply line from the pump and the fuel strainer (and when installing it), access to the nuts and bolts is blocked by the water pump, the forward mounting bracket, and the supply tube itself.

Safety wire is difficult to remove and install during removal and installation of the bypass-to-pump inlet tube because the nuts are close to the union.

There is limited access to the safety wire on the locking-ring bolts when disconnecting and connecting the locking ring. There is also little room to swing a mallet when using the fiber drift.

Removal and installation of the clamp that holds the inlet-temperature sensing tube and the burner-pressure sense line are blocked by a wire bundle.

Removal and installation of the fuel pump are blocked by the inlet-temperature sensing tube and the wire bundle.

Safety wire removal and installation is difficult when removing and installing elbows from the fuel pump because the nuts and studs are close to the union.

Limited access causes difficulty in positioning the crowsfoot to torque the elbow-union nuts.

Aaccess to the nuts that need to be torqued when attaching the mounting adapter to the fuel pump is blocked by the fuel-pump flange.

When inspecting the installation of the fuel pump, it is difficult to position feeler gauge, flashlight, and mirror because of surrounding components.

When installing the second-stage bypass-to-pump inlet line, it is difficult to safety wire two of the nuts that attach the elbow fitting to the pump because they are blocked by the line.

When the fuel supply line is connected to the main fuel strainer, the forward water-pump bracket obstructs the torquing and safety wiring of the attaching bolts.

Errors

Prolonged physical contact with fuel could be harmful to personnel.

Because of the crowded placement of components, tubes, and leads and because of sharp objects and safety wire, maintenance workers are likely to damage nuts and bolt heads, and to cut their hands.

Failure to support the fuel pump when removing it from the engine, or when installing it, could result in damage to the splined drive gear.

Failure to remove all of the old gasket from the sealing face could cause an oil leak.

Undertorquing could result in leaks.

Overtorquing or cross-threading could shear off threads.

Improper safety wiring could cause a fastener to loosen.

Improper use of the spline wear gauge could result in damage to the pump driveshaft and gearbox.

Failure to properly measure the gap between the accessory bracket and the lockring could cause pump failure.

Failure to properly measure the gap between the fuel pump adapter and the mounting pad could cause pump failure.

Starter Removal and Installation - J-57 Engine - KC-135 Aircraft

Behavior Objects

Breech cap
Disconnect handle
couldnon plugs
couldnon-plug pliers
Safety wire
Safety-wire pliers
Pneumatic duct
V-band clamp
Gaskets
1/4" ratchet handle
7/16" socket
Drain and filler plugs
Oil (MIL-L-7808)
7/8" crowsfoot
Torque wrench
Oil container
Rags
Starter
Mounting clamp
Retaining bolt in center of engine drive coupling
Tab washer
Spring retaining rings
Output shaft splines
Engine splines
Plastilube Moly No. 3
Acid brush
Lint-free cloth
Leather or soft plastic mallet

Constraints

The centrifugal-switch electrical connector has limited access because of the generator on one side and the hydraulic pump on the other side.

The oil-cooler tab severely restricts rearward movement of the starter during starter removal and installation.

The weight of the starter necessitates two workers for removal and installation.

The centrifugal-switch electrical connector must be attached and safety wired before the starter is installed. It cannot be installed later, as specified by the Job Guide.

It is not possible to "tap the entire circumference of the clamp with leather or soft plastic mallet," as specified by the Job Guide.

Errors

Prolonged physical contact with oil could be harmful to personnel.

It is easy to pull out the safety-wire holes on the electrical connectors. They are light and made of an aluminum alloy.

Failure to support the starter when removing it from the engine, or when installing it, could result in damage to the splined drive gear.

Failure to remove all of the old gasket from the sealing face could cause an oil leak.

Undertorquing could result in leaks.

Overtorquing or cross-threading could shear off threads.

Improper safety wiring could cause a fastener to loosen.

Failure to detect metal particles in the oil could result in starter failure.

Failure to detect a loose drive shaft could result in starter failure.

Failure to lubricate the drive shaft could result in starter failure.

Failure to seat the clamp could result in starter failure.

Failure to properly install the gasket at the inlet duct could result in air leaks.

Compressor Turbine Removal and Installation - J-57 Engine - KC-135 Aircraft

Behavior Objects

Turbine wheel
Lifting sling
Tie rods
Nuts
Guide tool(PWA 8539)
Fel-Pro C-200 antiseize compound
Internal and external splines
Oil (MIL-L-7808)
Petrolatum
No. 4-1/2 bearing and carbon seal
Acid brush
Hoist
Safety hook
Coupling wrench adapter (PWA 7317)
Coupling wrench collar (PWA 7489)
Torque adapter (PWA 7392)
Coupling wrench (PWA 6715)
Anchor-plate bar
Coupling wrench bar
Anchor plate
Breaker bar
Torque wrench
Hot-section pencil

Constraints

None

Errors

Failure to attach the lifting sling with the high mark in the proper position will result in the turbine wheel being out of balance.

Failure to install the guide tool properly could result in damage to the No. 4-1/2 bearing.

Failure to lubricate properly could result in equipment damage during installation and seizing during operation.

It is possible to damage the turbine wheel or injure personnel when using the hoist to install the turbine wheel.

If the turbine wheel is not manipulated carefully when seating it into its final position, carbon seals could be damaged.

Failure to rotate the compressor slowly as the turbine shaft is being installed could damage the No. 4-1/2 bearing or carbon seal.

Prolonged physical contact with oil could be harmful to personnel.

Failure to detect positive engagement of coupling pins could result in turbine-wheel failure.

Failure to withdraw the coupling wrench 1/2" to 3/4" will result in the coupling pins remaining in unlocked position.

Failure to detect continuous contact of turbine blades with the outer air-seal ring will result in turbine-wheel failure.

Fuel Pump Removal and Installation - F-101 Engine - B-1B Aircraft

(The Main Engine Control (MEC) and main fuel pump are removed together.)

Behavior Objects

1/4" universal socket
1/4" ratchet handle
12" extension
5/16" universal socket
Fuel supply line
B-nuts
Safety wire
Safety wire pliers
11/16" open-end wrench
PB1 tube
couldnon-plug pliers
Electrical connectors
Variable Stator Vane (VSV) feedback cable
Cotter pin
Support bracket
Bolts
Washers
Torque adapter
Bracket
Fuel manifold
Seal
9/16" open-end wrench
Compressor bleed air pressure tube
Compressor discharge pressure tube
5/8" open-end wrench
Augmenter signal tube
Inlet Guide Vane (IGV) servo fuel pressure tube
Main fuel discharge tube
Gaskets
Main fuel pump
MEC assembly
V-band clamp bolt
Allen wrench
V-band clamp
Packings
Scribe
7/16" dog bone
7/16" open-end wrench
JP-4 fuel
Oil (MIL-L-7808)
Packings
Torque wrenches
Allen-head wrench adapter
Dowel pin

3/8" ratchet handle
6" extension
Non-metallic mallet
Fiber drift
11/16" crowsfoot
3/4" open-end wrench
5/8" crowsfoot
7/8" open-end wrench
9/16" crowsfoot
3/4" crowsfoot
3/8" box wrench
1/4" box wrench
Diagonal-cut pliers
Needle-nose pliers

Constraints

Loosening or tightening the support tube on the VSV feedback cable is difficult because the support bracket limits wrench travel.

A special tool must be used to remove or install the upper-right bolt from the fuel manifold. A normal 1/4" box-end or dog bone is too long to fit into the available space; it is obstructed by the bracket.

Disconnecting or connecting the augmenter signal tube is difficult because wrench travel is restricted by the IGV servo fuel pressure tube.

Accessibility is very restricted at the V-band clamp bolt. It is difficult to remove the safety wire and to install it.

The weight of the main fuel pump and MEC assembly requires two workers for their removal.

Various tubes obstruct the removal and installation of the main fuel pump and MEC assembly.

It is difficult to disconnect or connect the main fuel pump and the MEC assembly because one nut is blocked by a filter housing. A dog bone couldnot be used on this nut when disconnecting it. A crowsfoot couldnot be used for torquing it.

To mate the main fuel pump drive shaft to the accessory gearbox, the V-band clamp must be held out of the way until the two components mate tightly.

It is difficult to tap the V-band clamp at some points on its circumference because there is little room to swing the mallet.

It is difficult to torque thye fuel manifold assembly mount bolts because the manifold bracket prevents torquing of the upper-right bolt.

Errors

Prolonged physical contact with fuel could be harmful to personnel.

The main fuel supply tube could be dented during removal.

It is possible to pull out the safety wire hole on the B-nut before disconnecting the PB1 tube and the bleed-air or discharge pressure tubes.

It is possible to pull out the safety wire hole on the jam nut before loosening the support tube on the VSV feedback cable.

It is possible to overspread the V-band clamp when removing or installing it and thereby fatigue its metal. It is also possible to round out the Allen hole in the bolt that tightens the clamp.

Failure to maintain the fuel pump level when inserting it or withdrawing it from the accessory gearbox could damage the splines.

Failure to use the two-wrench method--when appropriate to remove and install B-nuts (and torque them)--could cause damage to tubes or unions.

Undertorquing could result in leaks.

Overtorquing or cross-threading could shear off threads.

Improper safety wiring could cause a fastener to loosen.

Failure to properly inspect the V-band clamp before installation could result in clamp failure or fuel leaks.

It is possible to install an electrical connector with a bent pin.

Improper connection of the main engine control lever to the MEC lever arm will result in binding.

Starter Removal and Installation - F-101 Engine - B-1B Aircraft

Behavior Objects

7/8" open-end wrench
Case drain plug
Packings
7/16" open-end wrench
Oil (MIL-L-7808)
Oil container
Safety wire
Safety wire pliers
Torque wrenches
7/8" crowsfoot
Electrical connector
couldnon-plug pliers
Oil supply tube
B-nut
5/8" open-end wrench
Air turbine starter control valve
Nuts
Air turbine starter
V-band coupling
7/16" deep-well socket
1/4" ratchet handle
Hardness Critical Procedures (HCP) test equipment
Plastilube
Mallet
Fiber drift

Constraints

It is difficult to remove or install the air turbine starter control valve because the V-band coupling nut couldnot be removed or installed with a socket. The nut is too close to the starter exhaust duct. An open-end wrench must be used, and its movement is restricted.

The weight of the starter necessitates two workers for removal and installation.

Prolonged physical contact with oil could be harmful to personnel.

Improper torquing could cause leaks.

Improper safety wiring could cause leaks.

If the starter is not supported during removal and installation, splines could be damaged.

If he oil supply tube is bent during starter removal or installation, its B-nut could be hard to reattach.

Overtorquing or cross-threading could shear off threads.

Failure to line up the keyway on the electrical connector when installing it could result in bent pins.

Compressor Turbine Removal and Installation - F-101 Engine - B-1B Aircraft

Behavior Objects

Splines, rabbet, and threads of forward low-pressure turbine shaft
Lint-free cloth
Oil (MIL-L-7808)
Inspection gauge
Depth micrometer
Pencil and paper
Lift fixture
Hoist
Center-of-gravity fixture
Transport stand
Low-pressure turbine
Nuts
Bolts
5/16" box-end wrench
1/4" ratchet handle
5/16" universal socket
5/8" open-end wrench
1/2" speed handle
Outside micrometer
Push/pull fixture
Hydraulic cylinder
Shroud seals
Feeler gauge
Needle-nose pliers
Protector of No. 4 bearing carbon seal
Carbon seal and outer race area of No. 4 bearing
Heat gun
Heat duct and heat-duct thumb screw
Pilot tube
Ice bucket (chilling fixture 3C3320)
Gloves
Dry ice
Petrolatum
Surgical gloves
Rotor fan
Measurement tube
Calculator
Sweeney torque multiplier
Anti-seize compound (GP-460)
1/2"-drive breaker bar
Rings
Small inspection mirror
Torque wrench
3/4" open-end wrench
Brackets
Washers

Special ratchet-tool set (3C3121P02)
5/16" offset box-end wrench
Fairing screws
Apex
9/16" dogbone
7/16" dogbone
9/16" socket
7/16" socket
3/8" ratchet handle
5/16" dogbone
5/16" universal socket
5/16" box-end wrench
Torque adapter
Serrated retaining ring
Thermal ring
Coupling nut

Constraints

Measurements are difficuelt to make because of limited space at the seating rabbet.

There is limited space to pack petrolatum around the No. 4.

It is difficult to install the low-pressure turbine because it must be aligned by touch. It is impossible to visually align it with keyways.

Installirg outer fairing segments is difficult because there is limited space between the flange and the struts. About half of the 76 nuts are difficult to install.

Errors

Failure to clean the inspection gauge or failure to hold it flush against the face of the seating rabbet will result in incorrect measurement.

Improper use of the depth micrometer will result in incorrect measurement.

Failure to set the center-of-gravity fixture will result in damage to the engine and the turbine shaft.

Failure to install the push/pull fixture correctly could result in damage to the engine or injury to personnel.

Incorrect measurement of the turbine-shroud seals could result in suboptimal engine performance.

Overheating the bearing outer ring area could damage the outer ring or the carbon seal.

Failure to observe safety precautions could result in heat burns or dry-ice burns.

Failure to wear surgical gloves when touching the bearing could result in bearing failure.

Failure to remove dry-ice buckets carefully could damage the carbon seal.

Misalignment of the hoist could damage shaft housing.

Failure to release hydraulic pressure before removing the push/pull fixture could injure personnel and damage equipment.

Prolonged physical contact with oil could be harmful to personnel.

Failure to check the seating of the serrated retaining ring and the coupling nut could damage the turbine shaft.

APPENDIX B

LIST OF ACRONYMS

LIST OF ACRONYMS

Acronym	Definition
ADG	Accessory Drive Gearbox
AF	(United States) Air Force
AFB	Air Force Base
AFLC	Air Force Logistics Command
AFMPC	Air Force Military Personnel Center
AFS	Air Force Specialty
AGE	Auxiliary Ground Equipment
AL/HR	The Human Resources Directorate of Armstrong Laboratory
ASA	Applied Science Associates Inc.
ASVAB	Armed Service Vocational Aptitude Battery
ATC	Air Training Command
ATC/TT	The Technical Training staff of ATC
BCS	Baseline Comparison System
CAD	Computer-Aided Design
CAMT	Comparative Anatomy of Maintenance Tasks
CM	Consistently Mapped
DoD	Department of Defense
DoDD	DoD Directive
DPML	Deputy Program Manager for Logistics
DSC&Cs	Design-Specific Characteristics and Constraints
DTIC	Defense Technical Information Center
EPI	Electronic Principles Inventory
ETAP	Extended Task Analysis Procedure
FOD	Foreign Object Damage
HCP	Hardness Critical Procedures
HSI	Human-Systems Integration
I-level	Intermediate-level maintenance
IGV	Inlet Guide Vane
ILS	Integrated Logistics Support
IST	Initial Skill Training
JEM	Job Element Method
JFS	Jet Fuel Starter
LCOM	Logistics COmposite Model
LRU	Line Replaceable Unit
MAC	Military Airlift Command
MAJCOM	MAJor (Air Force) COMmand
MAJCOM/LG	MAJCOM logistics staff
MAJCOM/XPM	MAJCOM planning staff
MEC	Main Engine Control
MOE	Measure Of Effectiveness
M	Manpower
MPT	Manpower, Personnel, and Training
MPT&S	MPT and Safety
NOTAP	Navy Occupational Task Analysis Program
O-level	Operational-level maintenance
OJT	On-the-Job Training
OPR	Office of Primary Responsibility

LIST OF ACRONYMS (Continued)

Acronym	Definition
P	Personnel
PAQ	Position Analysis Questionaire
QTRD	QuesTech Research Division
R&M	Reliability and Maintainability
S	Safety
SAC	Strategic Air Command
SME	Subject-Matter Expert
SPO	System Program Office
SUMMA	Small-Unit Maintenance-Manpower Analysis
T	Training
TAC	Tactical Air Command
TCS	Task Characteristics System
TDS	Training Decisions System
TPDC	Training & Performance Data Center
TTM	Task Training Module
VM	Variably Mapped
VSV	Variable Stator Vane
WSAP	Weapon-System Acquisition Process