THE DEVELOPMENT OF DESIGN GUIDELINES FOR MAINTENANCE TRAINING SIMULATOR INSTRUCTOR AND STUDENT STATIONS

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ABSTRACT

Trainer-critical features (e.g., *performance monitoring, student recordkeeping*, etc.) for maintenance training simulators (MTSs) are typically derived during the front-end analysis phase of the acquisition process. The critical features (i.e., functional capabilities) are then designed into the MTS instructor station (IS) or student station (SS) by incorporating these requirements in the procurement specification. Although many of these features are common to most MTSs, a lack of standardization in their implementation has led to vastly different operating formats despite the same instructional intent. This paper discusses the procedures and the results of a research effort to develop a tool for acquisition personnel and design engineers to ensure the standardization of critical IS and SS features during the design of the MTS. The procedures used during this research effort included (1) developing a classification scheme for categorizing the various types of MTSs, (2) developing a MTS attribute taxonomy to identify and categorize MTS features, (3) performing a commonality analysis to assess the degree of functional similarity of features across and within MTS categories, and (4) conducting a survey of instructors to determine users' perceptions of the effectiveness of the various features. The results of the survey indicated that instructors gave high (perceived effectiveness) ratings to 13 of the 17 features assessed. These results were relatively consistent across the different types of MTSs indicating that the features were a function of instructional requirements rather than peculiar to specific MTS types. The findings were then used to derive a set of design guidelines for developing maintenance training simulator instructor and student stations.

INTRODUCTION

An examination of maintenance training simulators (MTSs) in the Navy inventory reveals a variety of device configurations and types (e.g., 2-D panel simulators, general purpose or "generic" simulators, 3-D replica simulators, videodisc-based systems). Undoubtedly, the different types of MTSs are a function of both the different training requirements derived during the front-end analysis phase of device procurement, and the unique characteristics of the end-equipment which is being simulated. Additionally, it is evident that auxiliary components such as instructor stations (ISs) and student stations (SSs) associated with these training systems, also vary considerably across MTSs, both in their design and how their functions are utilized. In spite of this diversification, many functional capabilities are common to most MTSs. However, these capabilities often exist in very different formats despite the same instructional intent.

By providing a means for standardizing critical functional capabilities across MTSs, the Navy may be able to (1) reduce procurement costs by eliminating the need to design ISs and SSs each time a new system is procured, (2) ensure that training-critical features are given proper consideration for inclusion during the design process, (3) improve integrated logistics support (ILS) by promoting commonality across MTSs, and (4) improve user acceptance by facilitating transferability of user skills across simulators. Standardization has been suggested by several authors (Carroll et al,. 1984; Hritz and Purifoy, 1984; Nauta, 1985) and is advocated by Naval Training Systems Center Instruction 4120.3D (1984).

The objective of this research effort was to derive a set of design guidelines, based upon past research and the data gathered from a survey of maintenance instructors, to support the development of MTS instructor and student stations. The intent of the guidelines is to ensure that appropriate consideration is given to incorporating critical functional capabilities during design and to maximize the standardization of these capabilities across MTSs. Although space limitations preclude a detailed discussion of the specific implementation recommendations, they are addressed in Carroll et al. (in preparation), which provides a thorough discussion of the guidelines for the functional capabilities and presents them in the form of a prime item development specification. This paper describes the approach taken in the research effort, discusses the results obtained, and identifies and defines those functional capabilities deemed critical for training by maintenance training instructors.

TECHNICAL APPROACH AND FINDINGS

The development of design guidelines to promote standardization of training-critical features was based upon a systematic approach which covered a number of issues related to MTS acquisition. The approach taken, and the findings associated with each phase of the effort are discussed below.

Classification of MTS Types

While several different definitions of MTS appear throughout the literature, for the purpose of this paper, MTS refers to a class of maintenance training devices that represent actual equipment or systems via computer controlled simulation of equipment operation and responses to user input. They are necessarily driven via an auxiliary computer and are designed to duplicate the performance characteristics of operational (i.e., actual) equipment under normal and malfunction conditions.

Since it was possible that some functional capabilities may have been peculiar to specific types of MTSs, it was necessary to examine the functional capabilities in the context of simulator type. A review of the maintenance training literature revealed the lack of a standard classification scheme for categorizing the different MTS types in a commonly accepted format. Thus, the initial step in this research effort involved the development of a classification system for categorizing MTSs by type. First, existing taxonomies in the literature were reviewed in terms of the classification categories used, descriptions of MTSs that fit within these categories, and the training objectives, characteristics, and functional fidelity associated with each category. Next, the taxonomies were evaluated in terms of comprehensiveness, clarity, parsimony, and ease of use -- factors which would promote application to the current effort. Finally, the reviewed taxonomies were synthesized, incorporating the strongest features of each such that the resulting classification system was composed of categories which were meaningful, non-redundant, and represented true discriminations between MTS types.

As a result of this analysis, four categories of MTSs emerged in the classification system: interactive video display simulators (IVDSs), panel simulators, model simulators, and stimulated actual equipment (SAE).

IVDSs include simulators which use computer-controlled videodisc images, computer-generated graphics, random-access slide systems, or any combinations of these formats. Typically, IVDSs are microcomputer controlled and consist of an interface device (keyboard/pad, touchscreen, mouse, etc.) and a video display unit for presenting images of the equipment the student is learning to maintain, and supporting information such as instructions, feedback, etc. An example of an IVDS is present in Figure 1.

Figure 1. Example of an Interactive Video Display Simulator.

Panel simulators (see Figure 2) are flat panels which contain simulated controls, test points, and displays. These components are configured in a manner which conveys their location and functional relationships in the actual operational equipment. Some controls, test points, and displays are functionally operative and are used for practicing hands-on maintenance tasks. Other components are merely photo-etched on the panel and are non-operative.

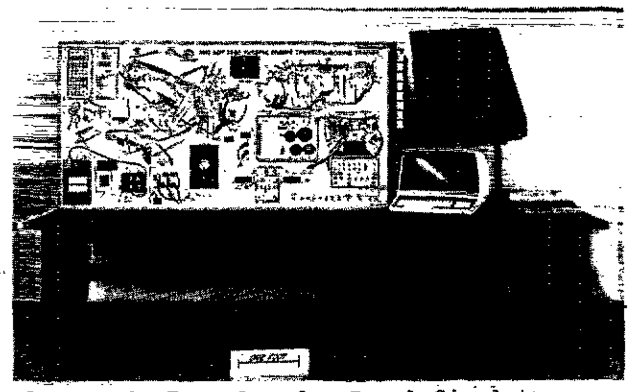


Figure 2. Example of a Panel Simulator.

Model simulators are 3-dimensional mockups or replicas of actual equipment. They may be full scale, under-scale, or enlarged representations. Typically, only those controls and displays essential to the tasks to be trained are functional; others are nonfunctional replicas or photo-etched. The functional components are used to support maintenance training via hands-on practice. An example of a model simulator is provide in Figure 3.

SAE refers to actual operational equipment which is directly stimulated by an auxiliary computer or some other input device (e.g., fault insertion device, signal generator). In the case of SAE, the actual equipment does not receive its input from normal sources, but rather from some external signal source, typically under computer control.

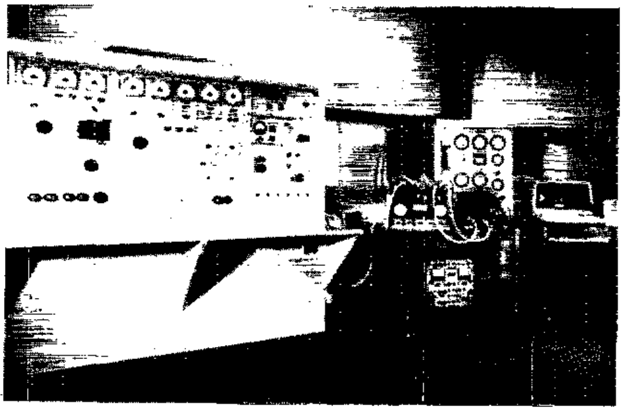


Figure 3. Example of a Model Simulator.

SAE is included in the classification system in order to provide a comprehensive taxonomy. SAE, which might be more accurately conceived of as a special case of Technical Training Equipment (TTE), is essentially off-the-shelf operational equipment which has been modified in some manner to enhance its training capacity. Because SAE is not truly a simulation system, the results discussed in this paper do not necessarily apply directly to SAE, but rather focus on IVDSs, panel simulators, and model simulators.

Selection of MTSs for Study

An initial list of 64 MTSs was identified for possible inclusion in this research effort. Several criteria were created which permited selection of a representative sample of MTSs from the initial candidate list. Each of the original 64 simulators was assessed against the criteria for incorporation in the study. The criteria used were:

(1) The device must be a dedicated maintenance simulator.

(2) The device must be used to train Navy and/or Marine Corps personnel.

(3) The device must have been used in a maintenance training course within the past 6 months.

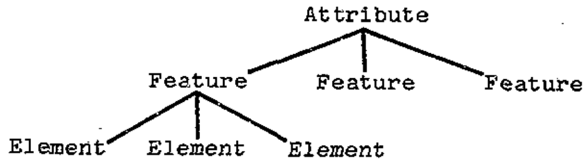
(4) The device must be computer-driven for training purposes.

(5) The device must contribute to the goal of obtaining a representative sample of MTS types.

Those simulators which met all of the criteria were selected for study. The final sample consisted of 16 MTSs: 3 IVDSs, 7 panel simulators, and 6 model simulators.

Development of an MTS Attribute Taxonomy

In order to organize the functional capabilities around a conceptual framework, it was necessary to develop an MTS atttribute taxonomy. A review of the literature did not reveal any existing attribute taxonomies. However, various MTS attributes and features evident throughout the literature, were extracted and analyzed. Based upon this examination and the authors' experience with MTSs, a three-tiered taxonomic hierarchy was generated. The taxonomy consisted of four global attributes at the "top" level of the hierarchy, several features associated with each attribute on the "middle" tier, and multiple elements which represented subcomponents of each feature at the "bottom" level. This relationship is depicted below.



Four MTS attributes emerged from the analysis: (1) Information/Training Management, (2) Instructional Features, (3) Human Factors Layout and Design, and (4) Computer System Characteristics. The first, Information/Training Management, refers to a capability that provides the instructor with the ability to perform training administration functions via the simulator's computer system. This attribute is composed of features such as system initialization, performance monitoring, performance measurement, system monitoring, report generation, student recordkeeping, student tutoring, training exercise selection, and training exercise creation/modification. Each of these nine features, in turn, is composed of several elements. For example, report generation is composed of (1) summary reports and (2) statistical profile; performance monitoring consists of (1) sensing and (2) recording.

The second attribute, Instructional Features, refers to mechanisms of the simulator and the associated software which enable the instructor to control critical aspects of the learning environment. Features associated with this attribute include student sign-in capability, malfunction insertion, freeze capability, augmented feedback, next activity control, cue enhancement, system parameter control, and training mode control. Again, each feature can be further subdivided into a number of elements.

Human Factors Layout and Design is the third taxonomy attribute. This refers to the design and layout of system components (both hardware and software) in order to effect an optimal user-system interaction. This attribute addresses those user-system interactions which are under software control and mediated through the simulator's input and output hardware. The features associated with this attribute are input/control devices, display devices, workstation layout and design, and user-system software interface.

Computer System Characteristics, the fourth attribute, addresses the hardware and software characteristics (configuration and function) of the MTS computer system and subsystems. The features of this attribute were derived from Hritz and Purifoy (1984) and include instructional systems software, computational subsystem hardware, computational subsystem software, and trainer support subsystems.

Commonality Analysis

In order to determine if certain MTS features were unique to a particular MTS type, a commonality analysis was performed. This phase of the research effort involved a determination of the frequency with which each of several features appeared in the MTSs studied. The determination was made via on-site administration of a survey questionnaire to instructors experienced with the MTSs used in the analysis.

Fifty-one instructors, distributed across the MTSs selected for study, completed surveys which were designed to ask which of the features were present on a given simulator. If the instructor indicated that a particular feature was present, he was then asked to indicate on two 7-point scales, the extent to which he believed that that feature contributed to training effectiveness and how frequently it was utilized. If the feature was not present, he was asked to indicate how desirable it would have been to incorporate it within the simulator. (The results of this "criticality" assessment are presented later). Only those 17 features associated with the first two attributes (Information/Training Management and Instructional Features) are addressed in this paper since they may be properly categorized as functional capabilities. Those features associated with the Human Factors Layout and Design attribute are not reported here since they cannot be categorized as functional capabilities per se, but rather represent design features such as input devices (e.g., keypads, switches), display devices (e.g., monitors, digital counters), workstation layout, and user-system interface. Additionally, the features associated with the Computer System Characteristics attribute were not addressed in the survey because it was believed that the instructors would not have the information necessary to give sufficient answers to items concerning aspects of computer system hardware and software.

The survey data which dealt with feature presence were extracted and arranged in a matrix in order to determine if feature presence exhibited any pattern either within or between MTS types. MTSs were grouped by type and presented along the horizontal axis. Features were presented along the vertical axis. A mark in a given cell of the matrix signified the presence of that feature in that simulator. Patterns of feature commonality were then examined by visually scanning the matrix. The commonality matrix is presented in Figure 4.

FUNCTIONAL CAPABILITIES	IVDS			PANEL							MODEL					
Initialization	■	■	■	■	■	■	■	■	■	■		■	■	■		■
Performance Monitoring	■	■	■	■	■		■	■		■	■	■	■	■		■
Performance Measurement	■	■	■		■	■	■		■		■	■	■		■	
System Monitoring	■			■	■			■		■	■	■	■	■		■
Report Generation	■	■	■		■			■		■			■			■
Student Recordkeeping		■	■										■			
Exercise Selection		■	■		■	■		■					■	■		■
Exercise Creation/Modification		■	■										■	■		
Malfunction Insertion	■	■	■	■	■	■		■	■	■	■			■	■	■
Freeze					■					■		■	■			■
Next Activity Control		■			■	■	■	■					■	■		■
System Parameter Control		■		■						■				■	■	
Training Mode Control		■			■						■					
Cue Enhancement	■	■		■						■			■	■		
Augmented Feedback	■		■	■	■	■	■	■						■		
Student Tutoring		■			■									■		
Student Sign-In		■		■	■									■		

Figure 4. Commonality of Functional Capabilities Across MTSs.

The results of the commonality analysis indicated that, in general, most of the 17 features (i.e., functional capabilities) were present in all MTS types. A relatively high level of feature commonality appeared both within and across MTS types. This pattern suggested that, in most cases, feature presence was independent of MTS type, and that these functional capabilities tend to cut across all MTSs, regardless of type. A few exceptions, however, should be noted. Student recordkeeping and training exercise creation/modification were virtually non-existent in the panel simulators; the freeze capability apparently did not exist in the IVDSs studied; and both training mode control and student tutoring each appeared in only three simulators (one IVDS, one panel, and one model).

Criticality Assessment

The survey data which assessed the criticality of each feature were analyzed and a criticality index was generated (i.e., a composite effectiveness - utilization - desirability score) for judging the importance of each feature. Instructor ratings were averaged for each feature and the average ratings were placed in one of three "criticality bands", indicating a low criticality rating (criticality index was less than or equal to 3.0), a neutral rating (index was between 3.0 and 5.0), or a high criticality rating (index was greater than or equal to 5.0) for that feature. The results are presented in Figure 5.

The results indicated that only one feature (system initialization) was given a low criticality rating. Three other features (student recordkeeping, freeze capability, and training mode control) were rated as neutral. The remaining 13 features were rated as high, suggesting a strong belief by instructors that these features contribute positively to training function.

FUNCTIONAL CAPABILITIES	MEAN CRITICALITY RATINGS: LOW 1	2	3	0 4	HIGH 5	6	7
Initialization			■				
Performance Monitoring						■	
Performance Measurement						■	
System Monitoring					■		
Report Generation					■		
Student Recordkeeping				■			
Exercise Selection						■	
Exercise Creation/Modification							■
Malfunction Insertion						■	
Freeze				■			
Next Activity Control						■	
System Parameter Control							■
Training Mode Control				■			
Cue Enhancement						■	
Augmented Feedback						■	
Student Tutoring						■	
Student Sign-In						■	

Figure 5. Mean Criticality Ratings for Functional Capabilities.

CRITICAL FUNCTIONAL CAPABILITIES: IDENTIFICATION AND DEFINITION

The 13 functional capabilities rated as highly critical by maintenance training instructors are presented below. These functional capabilities are briefly addressed here; a more thorough discussion is provided in Carroll et al. (in preparation).

Performance Monitoring refers to a computer system capability that automatically monitors (sense and records) student responses on a given training exercise. The advantage of this capability is that it allows responses to be recorded and later used to review specific areas of difficulty encountered by the student. This feature is a necessary prerequisite for both the performance measurement and report generation capabilities. The feature should be capable of being enabled/disabled by the instructor in order to conserve computer processing requirements when the feature is not needed.

Performance Measurement is a device capability that utilizes the simulator's computer system to compare student training performance to some pre-established criterion measure, assign a score, and store the results. Ideally, the instructor should have the control to adjust the criteria values against which student performance is judged. This capability allows the instructor to make qualitative judgements about a student's skill level.

System Monitoring is a capacity which provides the instructor with information about the control positions and display indications on the simulator during a training exercise. This allows the instructor to monitor student performance on-line, while the student is engaged in a practice scenario, and keep apprised of how well the student is performing the training task.

Report Generation enables the instructor to generate, via the system computer, a report of student or class performance, or the performance of students over several classes. The instructor can generate a report summarizing the results of statistical tests/measures of a student's performance in order to support feedback to the student. This information can assist the instructor in pinpointing areas of weakness in both the student and the training exercise.

Student Tutoring is a computer-based instruction capability that provides pre-programmed training exercises via the simulator's computer system. This capability allows the student to practice, usually in a self-paced fashion, pre-programmed training scenarios. Students can branch into remedial training for weak areas or delve deeper into areas of interest. This feature, therefore, provides an adaptive capability.

Training Exercise Selection and Training Exercise Creation/Modification (i.e., Training Exercise Control) is a capability that allows the instructor to perform one or more of the following: generate training exercises, select from a set of pre-programmed exercises, or modify existing training exercises. This provides the instructor with a great deal of flexibilty and control over the training environment. Also, it provides a technique for keeping training exercises updated and in line with changes in the actual system.

Student Sign-In is a capability that enables the student to identify himself/herself (usually for recordkeeping purposes) by entering a name or identification number into a file in the system's student monitoring software program. If it is intended that the simulator provide a means for recording, scoring, and/or storing student records for future use, then a sign-in capability is a necessary feature. This feature not only provides a means for establishing a unique repository for each student, but also provides a tracking function that allows the student to re-enter an instructional progression following a break or delay in the training sequence.

Malfunction Insertion/Selection is a necessary feature for MTSs which allows the instructor to create and/or select the malfunctions to be presented to the student during the training scenario. The instructor is able to insert pre-programmed malfunctions from a menu list, and often is able to create new malfunctions to meet new requirements.

Augmented Feedback is a training feature that provides the student with messages (i.e., knowledge of results) concerning the correctness of his/her input on a particular exercise. The message is usually presented via a video display screen. The comprehensiveness of the feedback can range from a buzzer indicating that an error has been committed, to a detailed explanation (text and graphics) of the error. A means for gradually reducing the feedback should be included for systematically reducing student dependency.

Next Activity Control enables the instructor to turn on or off the next activity pre-programmed for the student, or allows the instructor to select the next activity from a list of pre-programmed activities. As a result, the instructor can tailor a specific sequence of training scenario activities for a given student.

Cue Enhancement permits the highlighting (magnifying, intensifying) of stimuli or responses in order to draw attention to a particularly critical issue. On/off control of this feature should be available to the instructor.

System Parameter Control allows the instructor to set system parameter values prior to exercise commencement, or to input new system parameter values during a training exercise. Changes in parameters such as temperature, meter deflection, voltage, pressure, etc. can add to the challenge of a training scenario and let the instructor test the student's troubleshooting skills.

CONCLUSIONS

An analysis of survey data gathered on 51 maintenance training instructors revealed a "minimum" list of 13 critical functional capabilities that should be considered for implementation in maintenance training simulators. This list is by no means inclusive of all possible functional capabilities, but rather represents a common core of features (identified by knowledgable users) considered critical in supporting training effectiveness across most MTSs. The decision to add to this feature list for implementation of additional capabilities should be made on a case-by-case basis using information gathered during the front-end analysis phase of system procurement.

Diversification among MTS types will no doubt continue. Regardless of the multiple MTS configurations, however, certain critical functional capabilities should be designed into new systems. Furthermore, these functional capabilities should be implemented in a standard format across all MTS (to the extent possible) in order to reduce design costs, improve ILS through commonality, and promote transfer of user skills across training systems.

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