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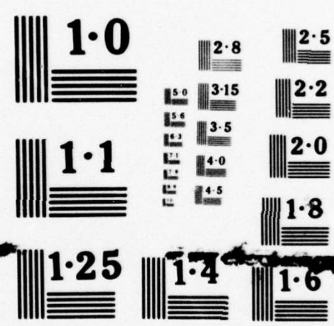
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AIR FORCE HUMAN RESOURCES LABORATORY

PERFORMANCE MEASUREMENT OF MAINTENANCE

By

John P. Foley, Jr.

ADVANCED SYSTEMS DIVISION
Wright-Patterson Air Force Base, Ohio 45433

December 1977

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AIR FORCE SYSTEMS COMMAND
BROOKS AIR FORCE BASE, TEXAS 78235

NOTICE

This report was submitted by Advanced Systems Division, Air Force Human Resources Laboratory, Wright-Patterson Air Force Base, Ohio 45433, under project 1710, with HQ Air Force Human Resources Laboratory (AFSC), Brooks Air Force Base, Texas 78235.

This technical report has been reviewed and is approved for publication.

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

This paper discusses the status of performance measurement (PM) for maintenance. During and after World War II, both Navy and Air Force maintenance training programs made extensive use of formal job task performance tests. But for economy reasons, these tests were later abandoned in favor of paper-and-pencil theory and job knowledge tests. Considering the results of later research, these actions were most unfortunate. This research has indicated that such paper-and-pencil tests do not indicate how well individuals can perform the tasks of their jobs. Even though PM were used extensively during and after World War II, there have been few systematic research and development (R&D) efforts concerning the refinement of PM for maintenance. This paper briefly describes the AFHRL R&D efforts for PM which have given due consideration to the man-machine interface. The rather promising

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personnel selection
psychology individual and group
system effectiveness measures
symbolic substitute job tests
video testing

Item 20 (Continued)

CONT → results of efforts to develop symbolic substitutes for PM are also presented. In addition, several problems concerning the research, development, and implementation of PM are discussed. The paper ends with proposals for future R&D efforts based on what has already been accomplished.

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SUMMARY

My paper discusses the status of performance measurement (PM) for maintenance.

1. During and after World War II, both Navy and Air Force maintenance training programs made extensive use of formal job task performance tests (JTPT). But for economy reasons, these tests were later abandoned in favor of paper-and-pencil theory and job knowledge tests.

2. Considering the results of later research, these actions were most unfortunate. This research has indicated that such paper-and-pencil tests do not indicate how well individuals can perform the tasks of their jobs. Table 1 of my paper indicates the correlations obtained from several studies which have compared JTPT to theory tests and to job knowledge tests. The table also includes correlations of JTPT with school marks. None of these substitute measures are sufficiently valid for use as substitutes for JTPT. I am convinced that the current unquestioned usage of such paper-and-pencil tests in field and training situations would be unforgivable if the people involved understood that their current testing practices are really invalid. No matter how cheaply paper-and-pencil job knowledge tests can be prepared or how easily they can be administered, such tests are not a bargain. Their results are almost meaningless in terms of ability to perform maintenance tasks.

3. Even though PM was used extensively during and after World War II and even though many valuable *ad hoc* PM efforts have been reported by the Army, Navy, and Air Force, there have been few systematic research and development (R&D) efforts concerning the refinement of PM for maintenance. A notable exception was the work of the Air Force Personnel and Training Research Center (AFPTRC) Maintenance Laboratory at Lowry AFB in the middle 50's. Another more recent systematic Army effort was the Vineberg effort, accomplished by HumRRO at Presidio of Monterey, California in the early 70's.

4. My paper briefly describes the AFHRL efforts which have given consideration to the man-machine interface. One important result of this consideration has been the evolution and articulation of a structure for handling maintenance functions and their complex relationships in a systematic manner. This structure includes (a) standard maintenance functions and action verbs, (b) a working definition of a maintenance task, and (c) schemes for handling the complexities of maintenance tasks. In the interest of time, I will limit my comments, here, to the task definition and a scheme for indicating dependencies among task functions.

5. Within the list of action verbs are a number of key action verbs (functions); such as checkout, align, adjust, calibrate, remove, replace, and troubleshoot. A key action verb, with an appropriate specific hardware unit as its predicate, becomes a *task statement.* Such a task statement represents a maintenance task which can be demanded by the existence and operation of a specific machine subsystem. A list of these functions is found in AFHRL-TR-73-43(I) (Joyce et al., 1973). This list includes functions which are found in both mechanical and electronic jobs. Some apply to only mechanical jobs and some apply to both.

6. Another matter of *serious* concern when developing and structuring PM for maintenance tasks is the interaction among the maintenance tasks for identical hardware. The scheme reflecting a four-level hierarchy of dependencies was developed. Figure 5 gives a graphic presentation of these dependencies among maintenance activities for an electronic hardware. An example of the dependency relationship is troubleshooting, which may include all of the activities above it.

7. Starting in 1969, the Advanced Systems Division of the AFHRL supported a modest program to provide the Air Force with the necessary tools for measuring the ability of maintenance personnel to perform the *key tasks* of their jobs. The contractor for this work was Matrix Research Company. The scope of this work was limited to the maintenance of electronic hardware at the organizational and intermediate levels. This program had two objectives: (a) to develop a model battery of JTPT together with appropriate scoring schemes for the measurement of the task performance ability of electronic maintenance personnel (an effort was to be made for the development of JTPT which could be easily administered), and (b) using the JTPT of this battery as criteria, to develop and try out a series of paper and pencil symbolic substitute tests which would hopefully have high empirical validity.

8. A model battery of 48 criterion referenced JTPT, and a test administrator's handbook were

developed for measuring ability to perform electronic maintenance tasks. Copies of the actual instructions for test subjects together with the test administrator's handbook are available from the Defense Documentation Center (DDC). The test administrator's handbook was developed with step-by-step detailed instructions so that an individual with a minimum of electronic maintenance experience could administer the tests.

9. After considering product, process, and time as to their appropriateness for scoring the results for each activity, it was decided that a test subject had not reached criterion until he had produced a complete, satisfactory product. This was a go, no-go criterion. Table 2 summarizes the number of tests, problems and scorable products by class developed for the Doppler Radar AN/APN-147 and Computer AN/ASN-35. The simple addition of numbers shown indicates that there are 48 tests, 81 problems, and 133 scorable products. But, these numbers tell us nothing in terms of the content of the tests. To say that one test subject accomplished 100 scorable products while another accomplished 90, tells us nothing about the job readiness of these individuals or about whether one is better than the other. The varieties of scorable products are so diverse that *any combination of them,* without regard to what they represent, is meaningless.

10. The only meaningful presentation of such information must be in terms of a profile designed to attach meaning to such numbers. A sample of part of such a profile is shown on Figure 6. This profile is not presented as the final solution to the profile problem for JTPT for electronic maintenance. It does contain most of the important information regarding a test subject's success on the full range of tests. It gives a meaningful picture of the subject's job task abilities as measured by the test battery, indicating the subject's strengths and weaknesses. The subject receives no "credit" for a problem unless he obtains all of the expected products. No attempt is made to combine these scores in terms of meaningless numbers.

11. There is no doubt that a battery of JTPT would require more training and on-the-job time of the test subjects, more equipment, and specially trained test administrators. It will be recalled that these were high among the reasons given for dropping PM from the Air Force and Navy maintenance training programs. Therefore, the availability of empirically valid symbolic substitute tests would be highly desirable. Even though previous attempts to develop such tests as the Tab test (Crowder, Morrison, & Demaree, 1954) had failed, it was our opinion that much more work could be done to improve symbolic maintenance tests as substitutes for JTPT. It was hypothesized that higher correlations could possibly be obtained by a different approach to the development of symbolic tests. For example, we felt that higher correlations could be obtained by adding realistic clutter to the cognitive aspects of troubleshooting tests, such as, using test equipment to obtain test point information. A companion graphic symbolic test was developed for each of the job activities for which a criterion referenced JTPT had previously been developed. Based on two limited validations, all of the graphic symbolic tests, with the exception of the symbolic test for soldering, indicated sufficient promise to justify further consideration and refinement. Due to a shortage of available subjects, the number of pairs of subjects was extremely small. All of these promising graphic symbolic tests, therefore, must be given more extensive validations using larger numbers of experienced subjects. An attempt, also, was made to develop video symbolic substitute tests, but this effort produced no promising results.

12. My paper also discusses several problems concerning the research, development, and implementation of PM. There is no doubt that there is a *great need* for PM in maintenance. One of the greatest problems is to develop the *demand pull* or necessary want to get newly developed technologies such as PM institutionalized. This is especially difficult when a technology requires fundamental changes in long existing programs, procedures, and attitudes of entrenched establishments. Operational organizations invariably attempt to implement a much "watered down" version of the technology and, consequently, obtain greatly "watered down" results. In some cases, only cosmetic changes to existing programs are reported as implementations. Currently it requires years of persistent effort (or *push*) on the part of the research community to get a technology properly institutionalized. A mechanism must be developed for the timely implementation of each new technology to ensure its integrity. A mechanism similar to that used for new weapons systems is recommended. Such a mechanism *must* make efficient and effective use of the "know-how" of the developers of the technology and make them responsible and accountable for its implementation. A new technology *should not* be turned over to a using command for its operation until it is in place, "debugged," and operational–just as a new weapons system is not turned over to an operational command until it has been "debugged" and proven to be ready for

operational use.

13. A number of related problems are also discussed. There is a well-developed paper-and-pencil test technology which is based on testing theory which is appropriate for the academic variety of education. This technology has been institutionalized and is well entrenched in the DOD personnel and training systems. All education test and measurement textbooks and courses reflect this technology. Psychological measurement texts also emphasize this technology. At least two generations of teachers and test and measurement psychologists have been trained in the use of this technology and, as a result, many have unquestioned faith in its application to any personnel measurement problem. Most of these people are products of the academic world. Few have had any "hands-on" experience in performing maintenance tasks. When the appropriateness of their technology for the measurement of maintenance ability is questioned, many members of this paper-and-pencil testing establishment become threatened and, therefore, defensive.

14. In spite of the extensive military history of usage, there is no PM establishment comparable to the paper and pencil test establishment. There are no college test and measurement courses (even in vocational education departments) which teach PM technology, and there are no textbooks devoted to the subject. The vocational educators have emulated their academic brethren by using their measurement texts. And there has only been a limited amount of systematic R&D concerning the development of a PM technology. Most of the current PM technology for maintenance is found in DOD technical reports.

15. Success in aircraft pilot training and other operator training has always been based on PM; that is, demonstrated ability to perform key job tasks. Consequently, these training programs have been designed to ensure success on PM. Such training has been characterized by an abundance of supervised practice of job tasks. *But* for maintenance personnel, paper-and-pencil theory and job knowledge tests have been used as the principal means for determining both the school and job success. As a result, maintenance training programs, both formal courses and career development courses (CDC), have come to be structured to ensure success on paper-and-pencil tests. This has resulted in the greater part of many so-called maintenance training courses taking on the verbal characteristics of academic education. *And* this has happened at the expense of supervised practice of job tasks.

16. The administration of PM requires time. Timewise, it certainly would be impossible to administer a PM to a maintenance man for every possible task that his hardware system might produce. This world of tasks and people must be sampled. The model PM, described previously, provides a sampling procedure based on major task functions such as checkout, align, adjust, troubleshoot, etc. But even this sampling across possible tasks resulted in *48* tests and 133 scorable products. It would be impractical to give any one test subject all of these 48 tests at any one time. Systematic sampling schemes must be developed across tests. The purposes for which PM results are to be used should be considered when developing sampling schemes. Such purposes of PM could include ascertaining (a) the job task proficiency of an individual, (b) the job effectiveness of a training program, and (c) the proficiency of a maintenance unit. Each of these purposes would require a different mix (or mixes) of tests and people. Some suggestions for such samplings can be found in AFHRL-TR-74-57(II) Part I (Shriver & Foley, 1974a). But it should be remembered that these are *suggestions* that must still be field tested. In the case of determining unit proficiency, some PM can be administered by on-line observation of tasks that are often repeated; such as, checkout. However, there will always be a requirement for off-line PM concerning critical, but seldom performed tasks. Whether the PM is performed on-line or off-line, the test administrator must use the same objective scoring procedures, the criteria of success being an acceptable *product*.

17. In spite of all of the evidence supporting requirements of PM for maintenance, it has been extremely difficult to obtain R&D funding for efforts to advance the PM technology. In addition, difficulty has been experienced in finding and retaining Air Force professionals with the necessary capability and interest to pursue an effective PM R&D program for maintenance. Such professionals are necessary, either for an in-house or contractor program. Any successful program in this PM area must be a long range program making use of existing expertise and aimed at expanding such expertise. "Off again, on again" efforts and/or jumping to a new contractor with every start will result in little improvement in PM technology.

18. Excessive maintenance costs are never going to be reduced as long as we don't have JTPT and/or empirically valid symbolic substitutes to ascertain how efficiently maintenance men perform the *tasks* of their jobs. In my opinion, the

lack of such measures of maintenance performance is a most serious *deficiency* in DOD. As such, R&D in this area should have an extremely high priority. For a long range R&D effort, five general areas of concentration are recommended; namely:

1. Refinement of Model JTPT Battery (Electronic Maintenance).

2. Refinement of Symbolic Substitutes (Electronic Maintenance).

3. Development of Model JTPT Battery (Mechanical Maintenance).

4. Development of Symbolic Substitutes (Mechanical Maintenance).

5. Job Aptitude Test Research Based on Results on JTPT.

19. Probably the most cost-effective approach for PM R&D (for electronic and mechanical maintenance) would be to concentrate on the development and refinement of JTPT on the use of key test equipments prior to proceeding with the other task functions of the proposed model test batteries. The use of general test equipment is a prerequisite to maintenance task functions such as alignment, calibration and troubleshooting. In addition, general test equipments usually have wide usage in such task functions across many hardware systems and there are a substantial amount of data which indicate that many maintenance men are weak in their test equipment ability. So, a general improvement in ability to use test equipment is an important and necessary factor for the general improvement of several maintenance task functions.

PREFACE

This report represents a portion of the exploratory development program of the Advanced Systems Division, Air Force Human Resources Laboratory, Wright-Patterson Air Force Base, Ohio.

The preparation of this report was documented under task 171010, Evaluating the performance of Air Force Operators and Technicians of project 1710, Training for Advanced Air Force Systems. The effort represented by this volume was identified as work unit 17101007. Dr. Ross L. Morgan was the task and project scientist.

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PERFORMANCE MEASUREMENT OF MAINTENANCE

I. PERFORMANCE MEASUREMENT HISTORY

Performance Measurement (PM) is not something new for the Defense Establishment. *But* many of the past PM efforts were not adequately documented. As a result, even the existence of many efforts has been forgotten. From personal experience during World War II, I know that the training establishments of both the Army Air Force and the Navy made extensive use of such measurements for such maintenance job tasks as checkout, alignment, and troubleshooting.

I do not know exactly when PMs were deemphasized in Navy maintenance training programs. However, in 1962, Harris and Mackie reported why PM was not being used in Navy training and field activities. Their report indicates that PMs were generally felt to require too much equipment and personnel time to be feasible.

In the Air Force, an active and substantial PM program continued until 1956. These measurement programs for the Air Training Command (ATC) of the Air Force and its predecessor, the Army Air Forces, included elaborate checkrooms. To increase measurement objectivity and decrease instructor bias, these checkrooms were manned by full-time test administrators. Their sole job was to develop and administer both written and performance tests. In most cases, these checkrooms were assigned their own hardware systems or subsystems which were used exclusively for PM. The PM required a substantial amount of equipment time, as well as test subject and test administrator time.

In 1956, almost all checkrooms were abolished to save money, equipment, and personnel. An often-used argument in favor of this action was that most civilian schools did not have checkrooms and that in civilian schools, the classroom, laboratory or shop instructors were responsible for measurement and grading, which was true. But the weakness in this argument is that in most cases, the shop instructors in civilian vocational schools did not have time to administer PM and also supervise shop exercises. As a result, the Air Force had a far superior and more valid measurement system than civilian vocational schools. Another argument was that the resources required for PM could not be justified since PMs were not part of the directed mission of ATC.

But no matter what the reason, there was a drastic decrease in the number of PMs used in ATC after 1956. The decrease or elimination of PMs resulted in complete reliance on paper-and-pencil theory and job knowledge tests as measures of school success. The absence of PM resulted in a decreased emphasis concerning "hands-on" equipment exercises in maintenance training programs. This was especially true for electronic maintenance training.

Early Air Force R&D for Maintenance PM

Although the use of PM in ATC *did* encourage the use of valuable "hands-on" training, the PM used did not reflect a systematic development process. As a result, their quality varied greatly from checkroom to checkroom. These and other weaknesses of the PM used in ATC were recognized by personnel of the Maintenance Laboratory of the Air Force Personnel and Training Research Center (AFPTRC) in the early 1950's. (This Maintenance Laboratory, located at Lowry Air Force Base, Colorado, was directed by Dr. Robert M. Gagné). This measurement research and development (R&D) continued until the demise of that laboratory in 1958.

One output of this effort intended for improvement of the development and administration of PM was "A Guide for Use in Performance Testing in Air Force Technical Schools" (Highland, 1955). However, this useful document was published too late. Due to the closing of checkrooms and the resulting deemphasis of PM, this guide received little or no use in ATC. However, if it had been followed, it certainly would have resulted in improved PM. One serious shortcoming of this guide, as viewed from today's vantage point, was the undue credence it gave paper-and-pencil measures.

In this regard, another important document of the Maintenance Laboratory reported the intercorrelations of measures concerning the proficiency of radar mechanics (Crowder et al., 1954). This was one of the early studies which reported extremely low correlations between results of PM and results of paper-and-pencil theory and job knowledge tests. During the 1950's and early 1960's, there were a number of other studies that produced similar findings. This matter will be discussed later.

It certainly was unfortunate for the quality of maintenance, that the use of PM was deemphasized. But at the time of these actions, much of the information now available about the weaknesses of paper-and-pencil tests for measuring school and job success had not been published. Even the most ardent supporters of checkrooms and PM in ATC had much more faith in the value of such paper-and-pencil tests than the subsequent research indicated. So under such circumstances, one cannot be too critical of the decision-makers who caused the elimination or deemphasis of PM. Perhaps, if such information had been presented at that time, ATC would have retained its checkrooms and its PM.

Early PM Efforts of the Advanced Systems Division (AFHRL)

With the abolishment of AFPTRC in 1958 and the resultant closing of its Maintenance Laboratory, the Air Force maintenance research responsibility was transferred to the Behavioral Sciences Laboratory (BSL) at Wright-Patterson Air Force Base, Ohio, but with greatly reduced manpower and monetary support. Since none of the research personnel were transferred with the responsibility, and all of the ongoing projects had been cancelled, the research program, conducted by the Training Research Division of BSL, was not a true continuation of work of the Maintenance Laboratory. (In 1968, the Training Research Division of BSL became part of the newly formed Air Force Human Resources Laboratory and eventually was renamed the Advanced Systems Division (AS) of AFHRL).

The maintenance R&D supported by BSL and its successor, AFHRL/AS, has been characterized by its emphasis on the maintenance man's *interface* with the hardware being maintained, as well as the improvement of his efficiency of performance on the job. Before an extensive program was started, an in-house analysis was made concerning the variables that contribute to the performance of maintenance (see Foley, 1973, pp. 14–16). Eventually three closely related R&D programs resulted, namely, performance measurement, job performance aids (JPA), and job (task) oriented training (TOT). In each of these programs, a determined effort was made to make maximum use of the previous R&D conducted by Army, Navy, and Air Force including the AFPTRC work. The planning of new work for each program was preceded by an in-depth review and analysis of the R&D literature.

In regard to the literature reviews and analyses made for PM (Foley, 1967, 1974), many valuable PM efforts have been reported by the Army, Navy, and Air Force. However, most of these efforts have not been *systematic* efforts, having as their prime objective the improvement of the state-of-the-art of PM. Rather, they have been *ad hoc* PM developments to support job oriented training research programs. A notable exception was the work of the AFPTRC Maintenance Laboratory. (Another more recent systematic Army effort, accomplished by the Human Resources Research Organization (HumRRO) was not covered in these reviews (Vineberg et al., 1970a, 1970b; Vineberg & Taylor, 1972a, and 1972b). As for civilian R&D, during the initial PM literature review (Foley, 1967), a serious attempt was made to identify and include the results of PM R&D from the civilian vocational education establishment. None was found.

A substantial outcome of the review of other PM efforts was a consolidation of research results concerning the correlations between results of PM for various maintenance tasks *and* paper-and-pencil theory tests, job knowledge tests, and school marks. As to their value for measuring ability to perform maintenance tasks, this research evidence gives a low rating to all of these paper-and-pencil based measures of school and job success. Table 1 shows correlations that have been obtained by comparing job task performance tests (JTPT) to theory tests and job-knowledge tests. The latter two are paper-and-pencil tests. Table 1 also includes correlations of JTPT with school marks. As indicated earlier, school marks have been heavily weighted with the paper-and-pencil test scores. An examination of this table indicates that the correlations of JTPT scores with theory test scores are generally somewhat lower than with job-knowledge tests. None of these measures are sufficiently valid for use as substitutes for JTPT (Foley, 1967, 1974).

II. THE MAN-MACHINE INTERFACE FOR MAINTENANCE

As stated previously, the maintenance R&D supported by AFHRL has emphasized the man-machine interface. From this point of view, PM for all personnel *associated* with machine systems must determine the ability of such personnel to perform tasks generated by the man-machine *interface*. Although there may be some overlap, most of the task functions demanded by a machine system of its operator personnel are *different* than those task functions demanded of its maintenance personnel. Herein, lies most of the unique, distinguishing characteristics of PM for maintenance. As a result, this section of my paper will be devoted to a discussion of the complexity of maintenance task functions.

Table 1. **Correlations Between Job-Task Performance Tests and Theory Tests, Job Knowledge Tests, and School Marks**

Researchers	Type of Job Task Performance Test (JTPT)	Theory Tests	Job Knowledge Tests	School Marks
Anderson (1962)	Test Equipment JTPT			.18–.33
Evans and Smith (1953)	Troubleshooting JTPT	.24 & .36	.12 & .10	.35
Mackie et at., (1953)	Troubleshooting JTPT	.38		.39
Saupe (1955)	Troubleshooting JTPT		.55	.56
Brown et al., (1959)	Troubleshooting JTPT	.40		
	Test Equipment JTPT		.29	
	Alignment JTPT		.28	
	Repair Skills JTPT		.19	
Williams and Whitmore (1959)	Troubleshooting JTPT			
	(Inexperienced Subjects)	.23		
	(Experienced Subjects)	.15		
	Adjustment JTPT			
	(Inexperienced Subjects)	.02		
	(Experienced Subjects)	.21		
	Acquisition Radar JTPT			
	(Inexperienced Subjects)	.03	.36	
	(Experienced Subjects)	.14	.22	
	Target Tracking Radar JTPT			
	(Inexperienced Subjects)	.24	.33	
	(Experienced Subjects)	.20	.38	
	Missile Tracking Radar JTPT			
	(Inexperienced Subjects)	.09	.15	
	(Experienced Subjects)	.19	.32	
	Computer JTPT			
	(Inexperienced Subjects)	.08	.24	
	(Experienced Subjects)	.06	.14	
	Total JTPT			
	(Inexperienced Subjects)	.14		
	(Experienced Subjects)	.20		
Crowder et al., (1954)	Troubleshooting JTPT	.11	.18–.32	

Past Human Factors Emphasis

But before discussing the characteristics of *task functions* for maintenance, it might be well to call attention to the fact that human factors establishments have given much more attention to the operator interface with machines than they have given to the maintenance personnel interface. Many actions are taken to maximize effective and efficient performance of the operator. Work stations are human-engineered to maximize the efficiency and comfort of the human operator. Major training facilities are provided, so that, operators can receive a large amount of supervised practice in performing typical tasks of their job. Graduation from training is based primarily on demonstrated ability to perform job tasks. And, periodic checks are made of the operator's ability to perform the critical tasks of his job. These, actions of course, are not all of the many efforts made to maximize the performance of human operators.

Generally, the human factors establishment has given little attention to the effectiveness and efficiency of the maintenance man's interface with hardware. The maintenance work, including the PM work of AFHRL/AS, has emphasized this neglected interface.

The Structure of the Man-Machine Interface for Maintenance

One of the results of our R&D for maintenance has been the evolution and articulation of a structure for handling maintence functions and their complex relationships in a systematic manner. This structure includes (a) standard maintenance functions and action verbs, (b) a working definition of a maintenance task, and (c) schemes for handling the complexities of maintenance tasks.

Standard Maintenance Functions and Action Verbs. The establishment of standard maintenance functions and action verbs has been one of the widely accepted results of the Air Force Systems Command's (AFSC) JPAs effort entitled "Presentation of Information for Maintenance and Operation" (PIMO). (Although the PIMO project was managed by the Space and Missile Systems

Organization (SAMSO) of AFSC, AS provided active participation and technical inputs during the entire project from 1966 through 1969. AS has incorporated the key findings and outputs of PIMO in its own JPA efforts.) Early in the PIMO project, it was found that many maintenance action verbs and functions were used by maintenance people, some with several different meanings. Part of this confusion was caused by the language used in maintenance technical orders which were written by different people and produced by many different hardware manufacturers. As a result, maintenance technicians themselves did not generally use precise language. A study was made to identify and define these action verbs. Where two or more verbs were used to indicate a similar action, the preferred verb was selected, based on the expressed preferences of a sample of maintenance men with a wide range of maintenance AFSCs. The use of the preferred verbs of this list is now a firm requirement of Air Force technical order specifications, as well as of recent Army and Navy specifications (see Joyce et al., 1973, pp. 97–142).

A Working Definition of a Maintenance Task. Within this list of action verbs are a number of key action verbs (functions). A key action verb, with an appropriate specific hardware unit as its predicate, becomes a *task statement.* Such a task statement represents a maintenance task which can be demanded by the existence and operation of a specific machine subsystem. A list of these functions is found in AFHRL-TR-73-43(I) (Joyce et al., 1973, pp. 19–20). This list includes functions which are found in both mechanical and electronic jobs. Some apply only to mechanical jobs and some apply to both.

Schemes for the Systematic Consideration of Maintenance Functions and Tasks. Three schemes have been developed for the systematic consideration of maintenance functions and tasks and the key factors that affect them.

Scheme One. A convenient model for categorizing these maintenance functions with relation to the type of hardware and the level of maintenance is presented in Figure 1. The common maintenance functions, already mentioned together with the usage of test equipment and handtools, are represented on one axis of the model. Since mechanical and electronic subsystems usually require a different variety of maintenance actions, they are represented by another axis. (In regard to this axis, mechanical maintenance could be further divided into two categories: (a) represented by hardware; such as jet engines, and (b) by hardware; such as airframes, and tank and ship hulls).

The third axis of the model represents the three levels or categories of maintenance now found in the military services. Organizational maintenance is the first level. It is usually aimed at checking out a whole machine subsystem and correcting any identified faults as quickly as possible. Flight-line maintenance falls in this category. A system is checked out. If it does not work, the line replaceable unit (LRU) or "black box" causing the malfunction is identified and replaced. This major component is then taken to the field shop (intermediate maintenance) where it is again checked out and the faults, authorized for correction, are corrected. The corrective actions, authorized at the intermediate level, vary greatly from system to system depending on the maintenance concept of each system. On some systems, the maintenance man will troubleshoot the black box to the piece-part level. In more modern equipment, he will identify a replaceable module made up of many piece parts. Some modules are thrown away, others sent to the depot for repair. Any LRUs which the field shop is unable, or unauthorized, to repair are sent to the depot for overhaul.

Organizational and intermediate level organizations are manned primarily by enlisted technicians whose average length of service is rather short (slightly more than 4 years in the Air Force). Depots are manned largely by civilian personnel with a much higher level of experience and longer, expected retention (service) time. Using this model, it has been possible to specify areas of concentration for study.

Since PM requirements for maintenance are so different for the various blocks indicated in this model, it is extremely important that PM researchers indicate the precise blocks of their concentration. To date, AFHRL/AS has concentrated on the shaded electronic portions of this model (Figure 1). The resultant model battery of 48 JTPT (together with their symbolic substitutes) will be described later. In addition, a battery of eleven JTPT were developed on an *ad hoc* basis (Shriver & Foley, 1975) for mechanical tasks at the organizational level of maintenance (see shaded portion of Figure 2). The HumRRO work, mentioned previously (Vineberg et al., 1970a, 1970b; Vineberg & Taylor, 1972a, 1972b) was concerned with mechanical hardware (tank and truck). The thirteen tests developed concerned the maintenance functions which are indicated by the shaded portions of Figure 3.

Scheme Two. Maintenance functions have limited meaning unless applied to specific hardware. A task identification matrix (TIM) is an extremely effective and necessary device for

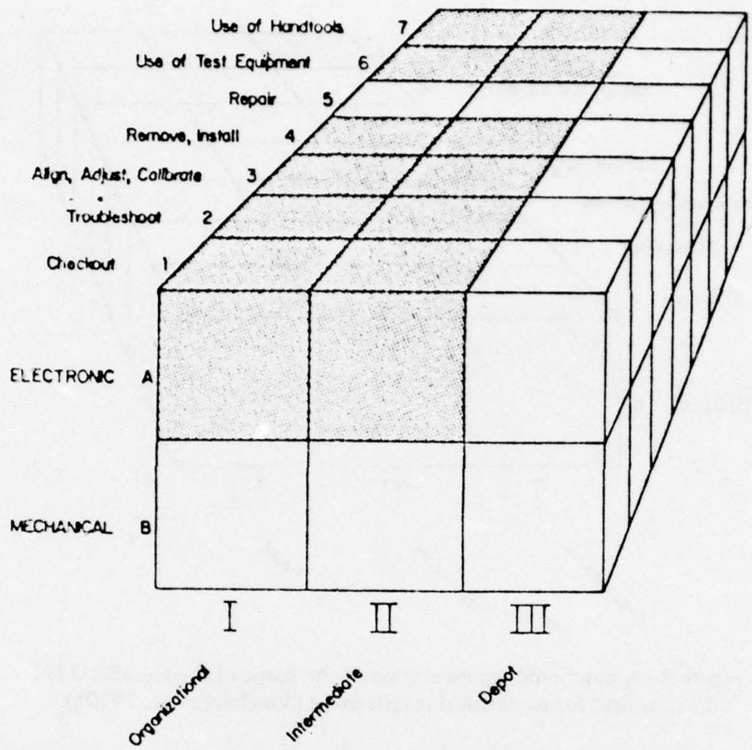

Figure 1. **A functional representation of the DOD maintenance structure (shaded portion indicates scope of AFHRL PM development for electronic maintenance).**

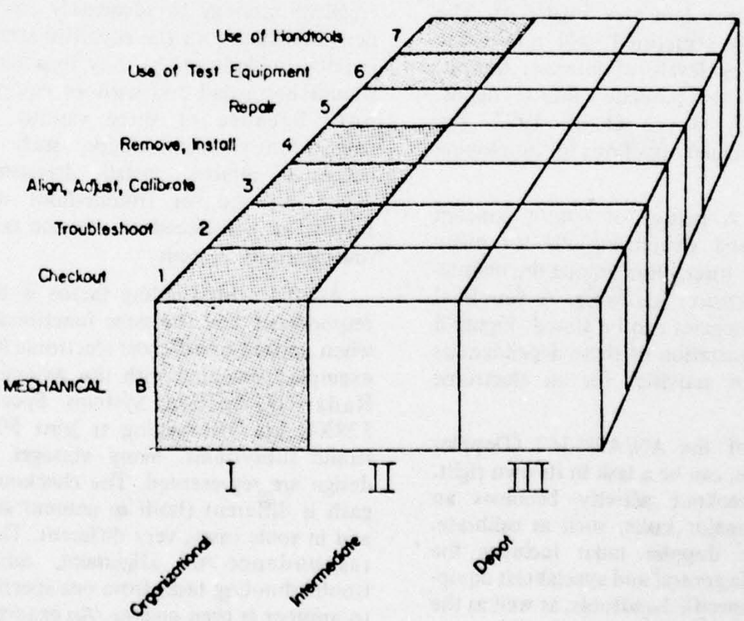

Figure 2. **A functional representation of the stops of AFHRL PM development for mechanical maintenance.**

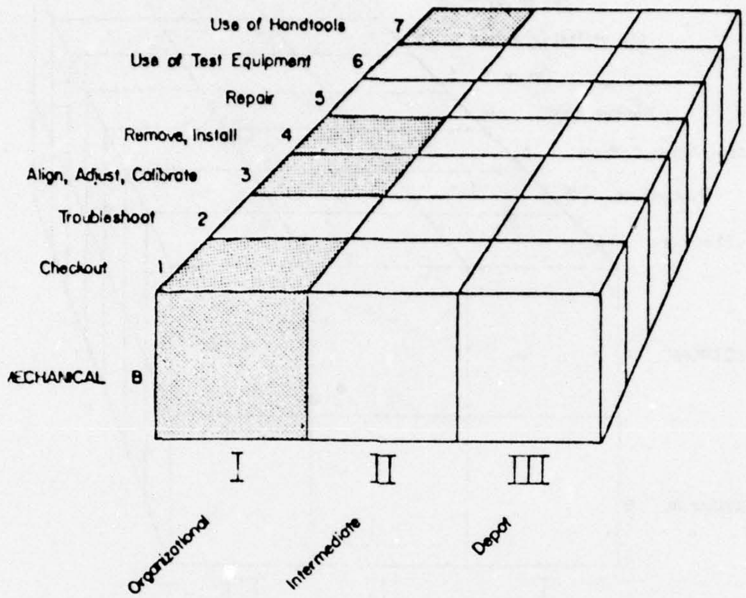

Figure 3. **A functional representation of the scope of the HumRRO PM development for mechanical maintenance (Vineberg et al., 1970b).**

interfacing these maintenance functions with the appropriate hardware units and thus identifying the maintenance tasks that are generated by a specific machine subsystem (see Figure 4). The TIM, when properly structured, will reflect the maintenance level or levels of interest; that is, organizational, intermediate and/or depot. AFHRL-TR-73-43(I) (Joyce et al, 1973, pp. 16–37) provides detailed directions for developing a TIM.

Scheme Three. A matter of *serious* concern when developing and structuring PM for maintenance tasks is the interaction among the maintenance tasks for *identical* hardware. A four-level hierarchy of dependencies can be stated. Figure 5 gives a graphic presentation of these dependencies among maintenance activities for an electronic hardware.

The checkout of the AN/APN-147 (Doppler Radar), for example, can be a task in its own right. But the same checkout activity becomes an element of other major tasks, such as calibrate. Calibration of the doppler radar includes the operation of specific general and special test equipments, the use of specific handtools, as well as the checkout activity. Troubleshooting of an electronic equipment, such as AN/APN-147, requires the use of general and special test equipments. It may require remove and install activities and/or adjust, align, and calibrate activities. Efficient troubleshooting practice usually requires the use of a cognitive strategy to adequately track the dependent activities (but the cognitive strategy in itself is not troubleshooting). Any troubleshooting task should begin and end with an equipment checkout. Because of these various and varying dependency relationships, such activities as checkout, remove, install, disassemble, adjust, align, calibrate, or troubleshoot cannot legitimately be considered as discrete tasks, even for one electronic system.

Another confounding factor is the false correspondence that the same functional verbs create when applied to *different* electronic hardware. For example, personnel with the Avionic Inertial and Radar Navigation Systems Specialist, AFSC 328X4, are maintaining at least 50 major electronic subsystems. Many vintages of hardware design are represented. The checkout activity for each is different (both in content and difficulty) and in some cases, very different. The lack of correspondence of alignment, calibration, and troubleshooting tasks from one specific equipment to another is even greater. An example of the lack of correspondence from one hardware to another (both having the same function) is the wide

Found in Troubleshooting	Code					System Hardware Item	Reference Designator	Adjust (1)	Align (2)	Calibrate (3)	Checkout/Troubleshoot (4)	Clean (5)	Disassemble/Assemble (6)	Inspect (7)	Lubricate (8)	Operate (9)	Remove/Install (10)	Repair (11)	Service (12)	(13)	Notes
✓	1	2				Control, Directional Listening C-8246	10	-	I*	-	I	I	I	-	-	-	0	I	-		*Resolver 1031 Alignment
	1	2	1			Knob		-	-	-	-	-	-	I	-	-	I	-	-		147971-1
	1	2	2			Panel, Control - Edge Lighted		-	-	-	-	-	-	I	-	-	I	-	-		159024-1
	1	2	3			Cover, Access		-	-	-	-	-	-	-	-	-	I	-	-		839691-801
	1	2	3	1		Stud, Turnlook Fastener							-	I	-	-	D	-	-		2-0-100
✓	1	2	4			Amplifier, Driver-Directional Listening	10A2	-	I	-	D	-		-	-	-	I	-			718436-801
✓	1	2	4	1		Capacitor	10A2 C15	-	-	-	-	-	-	-	-	-	D	-	-		CK06BX105K
✓	1	2	4	2		Relay, Armature	10A2 K1	-	-	-	-	-	-	-	-	-	D	-	-		35BC1206A2
	1	2	4	3		Insulator, Relay		-	-	-	-	-	-	-	-	-	D				7717-129N
✓	1	2	4	4		Resistor	10A2 R1	-	-	-	-	-	-	-	-	-	D	-	-		RCR07G223J3
✓	1	2	4	5		Resistor	10A2 R2	-	-	-	-	-	-	-	-	-	D		-		RCR07G223J3
✓	1	2	4	6		Resistor	10A2 R3	-	-	-	-	-	-	-	-	-	D	-	-		RCR07G105J3
✓	1	2	4	7		Semiconductor Device	10A2 CR5	-	-	-	-	-	-	-	-	-	D	-	-		JAN1N645
✓	1	2	4	8		Resistor	10A2 R32	-	-	-	-	-	-	-	-	-	D	-	-		RNS5D1783F
✓	1	2	4	9		Capacitor	10A2 C5	-	-	-	-	-	-	-	-	-	D	-	-		CM05FD221J03
✓	1	2	4	10		Transistor	10A2 Q4	-	-	-	-	-	-	-	-	-	D	-	-		JAN2N930
✓	1	2	4	11		Transistor	10A2 Q3	-	-	-	-	-	-	-	-	-	D	-	-		JAN2N930
	1	2	4	12		Insulator, Transistor		-	-	-	-	-		-	-	-	D	-	-		10197DAP
	1	2	4	13		Insulator, Transistor		-	-	-	-	-	-	-	-	-	D	-	-		10197DAP
✓	1	2	4	14		Capacitor	10A2 C13	-	-	-	-	-	-	-	-	-	D	-	-		CK06BX104K

Figure 4. **Example of a task identification matrix (TIM). Cell entries: – (dash) no maintenance task of this type is performed on this hardware item; 0 – task of type, performed at organizational level; I – task, performed at intermediate level; and D – task, performed at depot level.**

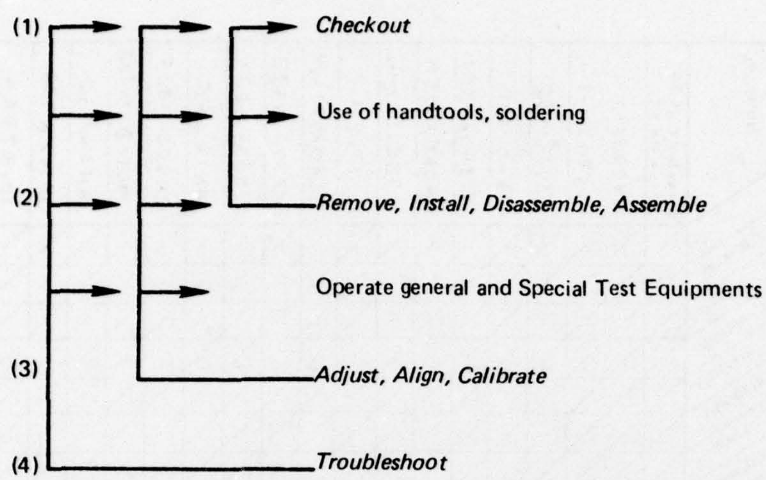

Figure 5. **Indicating the dependencies among maintenance functions for electronic hardware (functions italicized).**

difference in the content and difficulty of troubleshooting tasks between two doppler radars. The AN/APN-147, which is used on the C-130 and C-141, has approximately 14,000 shop replaceable units (SRU) whereas the inertial doppler navigation equipment (IDNE) on the C-5 has only 28. This lack of correspondence of functions across electronic hardware makes it difficult to generalize from results of PM from one electronic hardware to another. One exception is in the area of general test equipment, which may be used in performing maintenance tasks across many hardware subsystems.

The examples given are characteristic of many of the electronic maintenance AFSCs. Similar problems in complexity of maintenance functions and tasks are found in mechanical hardware, but to a lesser degree.

Maintenance Functions and Tasks and Traditional Psychological Variables

In this consideration of the characteristics of maintenance functions and tasks, the psychological language normally used by human factors specialists in describing the activities of operator personnel has not been used. There are several reasons for this nonusage. Such analyses would be extremely expensive to generate and would be of little value to maintenance personnel and training people. In most cases a task (generated by a maintenance functional verb plus its specific hardware unit) is considerably different from another task (generated by the same functional verb plus a different hardware unit). A separate human factors analysis would have to be made for each of these tasks. Some maintenance specialties now include over 50 major electronic subsystems–most of which produce hundreds of such tasks.

A traditional human factors type of task analysis for such tasks, if properly utilized, would probably be of great value during the original design of a specific hardware or for the design of realistic training simulators. But most of maintenance personnel interface with such subsystems long after their design. The type of task analysis required for the maintenance man calls for a different language. The *functions* used in this discussion of PM are, therefore, based on a common language that is familiar to (if not always completely understood by) a wide range of DOD personnel directly or indirectly associated with maintenance.

III. DEVELOPMENT OF PM AND SYMBOLIC SUBSTITUTES FOR PM

Starting in 1969, the Advanced Systems Division of the AFHRL supported a modest program to provide the Air Force with the necessary tools for measuring the ability of maintenance personnel to perform the *key tasks* of their jobs. The scope of this work was limited to the maintenance of electronic hardware at the organizational and intermediate levels (see shaded portion of Figure 1). This program had two objectives: (a) to develop a model battery of job task performance tests (JTPT) together with appropriate scoring schemes for the measurement of the task performance ability of electronic maintenance personnel (an effort was to be made for the development of JTPT which could be easily administered), and (b) using the JTPT of this battery as criteria, to develop and try out a series of paper-and-pencil symbolic substitute tests that would hopefully have high empirical validity.

Criterion Referenced Job Task Performance Tests

A model battery of 48 criterion referenced JTPT and a test administrator's handbook were developed for measuring ability to perform electronic maintenance tasks. Copies of the actual instructions for test subjects together with the test administrator's handbook are available from the Defense Documentation Center (DDC) as AFHRL-TR-74-57(II) Part II (Shriver et al, 1975). The test administrator's handbook was developed with step-by-step detailed instructions so that an individual with a minimum of electronic maintenance experience can administer the tests.

The battery includes separate tests for the following classes of job activities: (a) equipment checkout, (b) alignment/calibration, (c) removal/replacement, (d) soldering, (e) use of general and special test equipment, and (f) troubleshooting. The Doppler Radar AN/APN-147 and its Computer AN/ASN-35 were selected as a typical electronic system. This system was used as the test-bed for this model battery. The soldering and general test equipment JTPT are applicable to all electronic technicians. The other tests of the battery apply to technicians concerned with this specific doppler radar system. A detailed description of the development and tryout of these JTPT is given in AFHRL-TR-74-57(II) Part I (Shriver & Foley, 1974a). Each class of activity (for which JTPT were developed) contains its individual mix of behaviors, but it is not mutually exclusive. As indicated in Figure 5 and Table 1, a four-level hierarchy of dependencies exists among them.

After considering product, process, and time as to their appropriateness for scoring the results for each activity, it was decided that a test subject has not reached criterion until he has produced a complete, satisfactory product. This was a go, no-go criterion.

Table 2 summarizes the number of tests, problems and scorable products by class developed for the AN/APN-147 and AN/ASN-35. The simple addition of numbers shown in Table 2 indicates that there are 48 tests, 81 problems, and 133 scorable products. But, these numbers tell us nothing in terms of the content of the tests. To say that one test subject accomplished 100 scorable products, while another accomplished 90, tells us nothing about the job readiness of these individuals or that one is better than the other. The varieties of scorable products are so diverse that any combination of them, without regard to what they represent, is meaningless. The only meaningful presentation of such information must be in terms of a profile designed to attach meaning to such numbers. A sample of such a profile is shown in Figure 6.

This profile is not presented as the final solution to the profile problem for JTPT for electronic maintenance. It does contain most of the important information regarding a test subject's success on the full range of tests. It gives a meaningful picture of the subject's job task abilities as measured by the test battery, indicating the subject's strengths and weaknesses.

An examination of the profile (Figure 6) indicates that most of the tests in this battery contain

Table 2. **Tests, Problems, and Scorable Products**

Class	Code	Tests	Problems	Scorable Products
1. Checkout	CO	2	2	2
2. Physical Skill Tasks (soldering)	PT	2	5	17
3. Remove and Replace	RR	10	10	20
4. Test Equipment	SE	7	37	67
5. Adjustment	AD	6	6	6
6. Alignment	AL	10	10	10
7. Troubleshooting	TS	11	11	11
Total	7	48	81	133

only one problem. For example, there are two checkout tests, having one problem each and there are eleven troubleshooting tests having one problem each. There are two soldering tests; one has two problems and the other has three. The volt-ohmmeter (VOM) test has 20 problems.

The subject receives no "credit" for a problem unless he obtains all of the expected products. No attempt is made to combine these scores in terms of meaningless numbers.

The hierarchy of dependencies discussed previously (Figure 5) has implication for the order in which tests are administered, as well as for diagnostics. For example, since troubleshooting includes the use of test equipment and other activities in the hierarchy, logic would dictate that in most training situations the administration of the tests for the subactivities would precede the troubleshooting tests and that a test subject would not be permitted to take the troubleshooting tests until he had passed these other subtests. Under some circumstances, one may wish to reverse the process. A subject who successfully completes selected troubleshooting or alignment tests can be assumed to be proficient in his use of test equipment and checkout procedures. These dependencies are displayed on the left-hand side of the profile (Figure 6).

Due to the unavailability of a sufficient number of experienced test subjects at the time of the tryout of the JTPT battery, the tryout was not as extensive as planned. The limited tryout did indicate that the tests, as developed, are administratively feasible. Their continued use, no doubt, would result in further modifications and improvements.

Development of Symbolic Substitutes

There is no doubt that a battery of JTPT would require more training and on-the-job time of the test subjects, more equipment, and specially trained test administrators. It will be recalled that these were high among the reasons given for dropping PM from the Air Force and Navy maintenance training programs. Therefore, the availability of empirically valid symbolic substitute tests would be highly desirable. Even though previous attempts to develop such tests as the Tab test (Crowder et al., 1954) had failed, it was our opinion that much more work could be done to improve symbolic maintenance tests as substitutes for JTPT. It was hypothesized that higher correlations possibly could be obtained by a different approach to the development of symbolic tests. A study of the Tab tests (Crowder et al., 1954, see Table 1) indicated that the JTPT used as the criterion measures contained many distractions and interruptions to the subject's troubleshooting strategy (cognitive process); such as, using test equipment to obtain test point information. In addition to such interruptions in the cognitive process, the subject can obtain faulty test point information by the improper use of his test equipment. In the symbolic substitute Tab tests, all of these potential pitfalls of the actual task were avoided. The subject was given a printed test point readout. It was hypothesized that the injection of job equivalent pitfalls into symbolic substitutes possibly would increase their empirical validity.

Based on these hypotheses, a battery of symbolic tests was developed under contract with the Matrix Research Company of Falls Church, Virginia. A companion graphic symbolic test was developed for each of the job activities for which a criterion referenced JTPT had previously been developed. Based on two limited validations, all of the graphic symbolic tests, with the exception of the symbolic test for soldering, indicated sufficient promise to justify further consideration and refinement. Table 3 indicates the correlations obtained from these validations. Due to a shortage of available subjects, the number of pairs of subjects was extremely small. All of these promising graphic symbolic tests, therefore, must be given more extensive validations using larger numbers of experienced subjects.

The validation of any such symbolic test requires the administration of a companion JTPT as a validation criterion. As a result, a validation is an expensive process in terms of equipment and experienced manpower. The troubleshooting symbolic tests require the most extensive refinement. Several suggestions are made for improving their empirical validity. A complete description of these symbolic test efforts can be found in AFHRL-TR-74-57(III) (Shriver & Foley, 1974b). An attempt, also, was made to develop video symbolic substitute tests, but this effort produced no promising results. (Shriver et al., 1974).

Even if graphic symbolic substitutes of high empirical validity can be produced, the use of symbolic substitutes will never, in my opinion, dispense with the requirement for the liberal administration of actual JTPT to maintenance personnel. We can never include all aspects of an actual performance of a task in a paper and pencil symbolic representation of that task, but our work indicates that we can come much closer than has been done in the past.

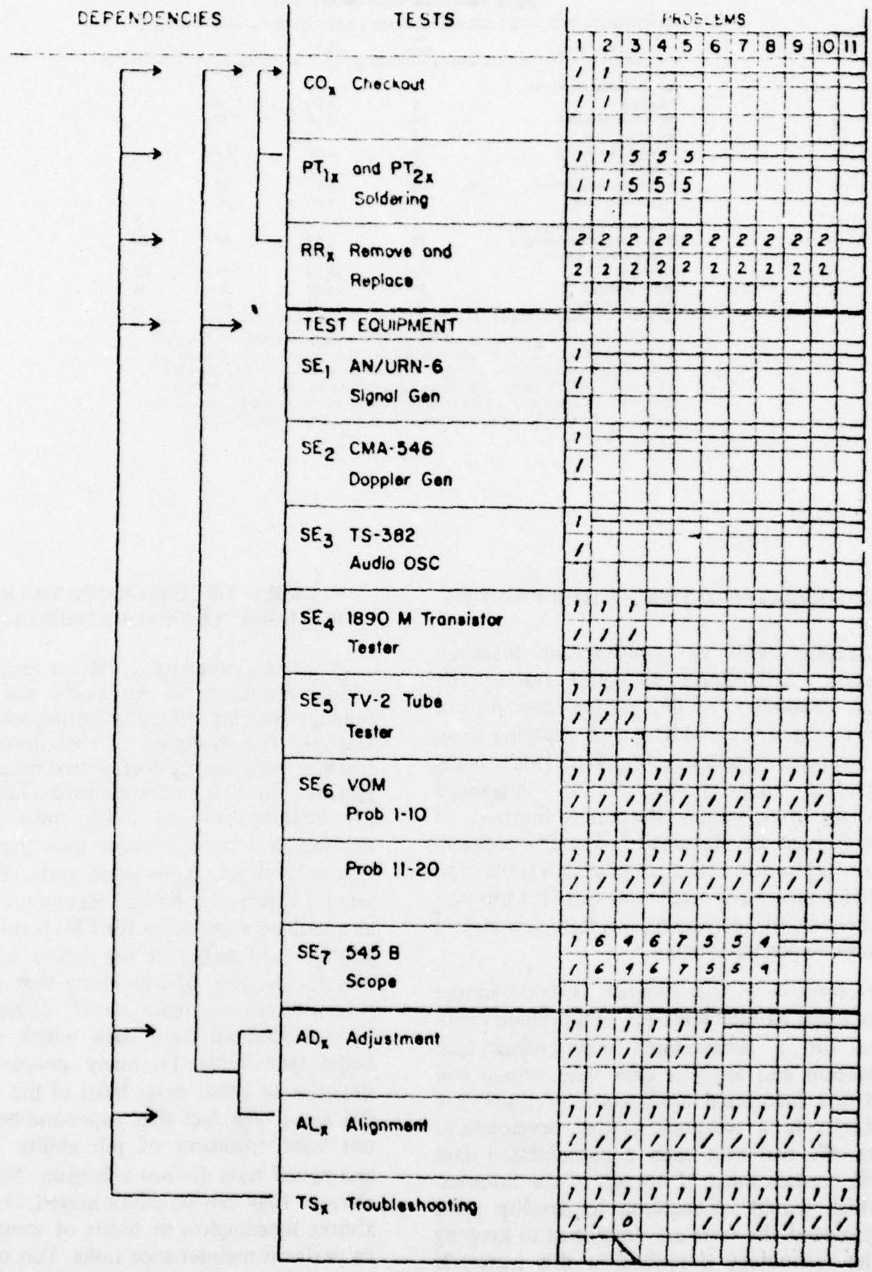

Figure 6. **A profile for displaying the results obtained by an individual subject from a battery of Job Task Performance Tests concerning an electronic system – the AN/APN-147 and the AN/ASN-35. This represents the profile of an individual who has successfully completed most of the battery.**

Table 3. **Indicates the Number of Pairs Used as Well as the X^2 and the Correlations Obtained during Two Small Validations of Symbolic Tests**

Test Area	N Pairs	X^2	ϕ	r_t
Novice Subjects (Altus)				
Checkout	4	4.00	1.00	–
Remove & Replace	14	2.57	.43	–
Soldering Tests	4	0	0	–
General Test Equip	6	2.67	.67	–
Special Test Equip	6	.67	.33	–
Alignment/Adjustment	19	6.37	.58	–
Troubleshooting	9	1.00	–.33[a]	–
Experienced Subjects (TAC)				
Overall Troubleshooting	30	6.53	.41	.68
Chassis (Black box)				
Isolation	30	16.33	.73	.81
Stage Isolation	30	3.33	.33	.46
Piece/Part Isolation	15	.07	.07	.16

[a] This negative correlation was probably due to a number of deficiencies such as (1) deficiencies in the Fully Proceduralized Job Performance Aids provided the subjects, (2) deficiencies in the sequencing of the troubleshooting JTPT in relation to the sub tests in the JTPT battery, (3) maintenance difficulties with the AN/APN-147 AN/ASN-35 system, and (4) difficulties with the content and administration of test equipment pictorials provided in the original troubleshooting symbolic tests.

IV. CONSOLIDATED DATA BASE TO SUPPORT PM

In keeping with its man-machine interface orientation, AFHRL/AS is demonstrating the technical feasibility of integrating five human resources related technologies and applying them during weapons system development. This is being accomplished under Project 1959, "Advanced System for the Human Resources Support of Weapon System Development." The five technologies are: (a) human resources in design trade offs, (b) maintenance manpower modeling, (c) job performance aids, (d) instructional system design, and (e) system ownership costing.

One objective of this program is to determine the data input requirements for, and prepare specifications for, a consolidated maintenance task identification and analysis data base, which will support the integrated application of these five technologies in a weapons system development program. We feel that such a consolidated data base will contain most, if not all, of the information which would be required to develop good JTPT provided the tests are developed in keeping with the technology described in this paper. If such a data base is demonstrated to be technically feasible and if it is routinely made a requirement in weapons system development contracts, it will provide considerable assistance in developing maintenance performance tests for new weapons systems.

V. PROBLEMS CONCERNING THE RESEARCH, DEVELOPMENT AND IMPLEMENTATION OF PM

As stated previously, PM for maintenance had widespread usage in Air Force and Navy maintenance training programs during and after World War II. The dropping of such tests from these training programs reflected two interacting prime factors. The first prime factor is a *fact*; that is, PM for maintenance are much more expensive to develop and to administer than paper-and-pencil theory and job knowledge tests. However, the second factor, the general acceptance of such tests as adequate substitutes for PM, is not a fact but a widely held *belief*. I use belief here with the precise meaning of something that is held to be true without adequate *proof*. Although we now have substantial hard data which disprove this belief (see Table 1), many people seem to be unaware of these data. Most of the objections to PM ignore the fact that paper-and-pencil tests are not valid measures of job ability. Such paper-and-pencil tests are not a bargain. No matter how cheaply they can be administered, their results are almost meaningless in terms of measuring ability to perform maintenance tasks. This state of affairs has contributed to a number of other problems.

1. There is a well-developed paper-and-pencil test technology which is based on testing theory which is appropriate for the academic variety of education. This technology has been institutionalized and is well entrenched in the DOD personnel

and training systems. All education test and measurement textbooks and courses reflect this technology. Psychological measurement texts emphasize this technology. At least two generations of teachers and test and measurement psychologists have been trained in the use of this technology and, as a result, many have unquestioned faith in its application to any personnel measurement problem.

Most of these people are products of the academic world. Few have had any "hands-on" experience in performing maintenance tasks. When the appropriateness of their technology for the measurement of maintenance ability is questioned, many members of this paper-and-pencil testing establishment become threatened and, therefore, defensive.

2. In spite of this extensive military history of usage, there is no PM establishment comparable to the paper-and-pencil test establishment. There are no college test and measurement courses (even in vocational education departments) which teach PM technology, and there are no textbooks devoted to the subject. The vocational educators have emulated their academic brethren by using their measurement texts. There has only been a limited amount of systematic R&D concerning the development of a PM technology. Most of the current PM technology for maintenance is found in DOD technical reports.

3. Just as human factors resources have favored the operator's interface with hardware *over* that of the maintenance man's interface, the personnel and training resources have heavily favored the operator. This has been especially true with regard to the aircraft pilot. DOD still contains elements of a caste system which relegated the maintenance man to the status of a "grease monkey." This is a reflection of a deep-seated culture bias in our society against any group who gets their hands dirty while earning their living. This bias has been extremely strong in the management and academic establishments. The importance of the maintenance man and his problems has been consistently downgraded, perhaps not by word, but certainly by the allocations of resources. No matter how costly, the operator has always been provided the necessary hardware and hardware simulators, as well as the necessary PM, to ensure his ability to perform the tasks of his job. Few such facilities have been provided for the maintenance function–one result has been an *effective* but inefficient and costly maintenance system. Costly maintenance is directly translated into excessive life cycle costs of ownership of hardware.

4. Success in aircraft pilot training and other operator training has always been based on PM; that is, demonstrated ability to perform key job tasks. Consequently, these training programs have been designed to ensure success on PM. Such training has been characterized by an abundance of supervised practice of job tasks. But for maintenance personnel, paper-and-pencil theory and job knowledge tests have been used as the principal means for determining both the school and job success. As a result, maintenance training programs, both formal courses and career development courses (CDC), have come to be structured to ensure success on paper-and-pencil tests. This has resulted in the greater part of many so-called maintenance courses taking on the verbal characteristics of academic education. This has happened at the expense of supervised practice of job tasks.

5. A like imbalance of emphasis is reflected in the more stringent PM certification required of the *operator*. A pilot for example, is certified on the basis of his demonstrated performance before he is permitted to fly a specific type of aircraft, and his proficiency is checked periodically as long as he is required to fly that aircraft. *But* a maintenance man receives no such certification of his ability to perform the maintenance tasks required of him by the same aircraft.

Rather than an equipment-specific PM certification, an "occupational" certification based on paper-and-pencil job knowledge tests has been substituted for maintenance personnel. Many maintenance "occupations" cover a large number of systems or subsystems. An individual maintenance man usually works on one or two such systems or subsystems. Tests for occupations have, therefore, been general in nature. Most of the personnel and training measures for maintenance men in all three services have been of the paper-and-pencil job knowledge variety. However, the Army now has a policy for including PM on specific job tasks in its maintenance personnel system (Maier et al., 1976). This policy is only in an early stage of implementation.

Returning to the pilot/maintenance man comparison, it is true that an improficient pilot might destroy a whole aircraft. Thanks to good checkout procedures, it is highly improbable that a maintenance man's actions would cause the sudden destruction of a whole aircraft. However, over a period of time an improficient maintenance man can do the equivalent, on a piece-by-piece basis, by the damage he can cause by his lack of skill, and by his consumption of unnecessary spare parts to correct malfunctions. Certification by PM would certainly improve the efficiency of maintenance.

6. Closely related to this lack of meaningful certification for maintenance, is the lack of accountability. The target of the personnel, training and tech data establishments should be to ensure the maintenance man's ability to perform the tasks of his job efficiently. But our personnel measures do not ascertain how many hits and misses we make—nor what is causing our misses. As a result, no one is being held accountable for the effectiveness of their contributions in terms of efficiency of job task performance. Many people in these establishments can see no reason for adopting improved technologies such as TOT and JPA—because they have never been held accountable for hitting the job performance target. We, therefore, require the use of valid job task performance measures to provide the bases for such required accountability. But such a possibility becomes very threatening to many people in these establishments.

7. In spite of all of the evidence supporting requirements of PM for maintenance, it has been extremely difficult to obtain R&D funding for efforts to advance the PM technology. In addition, difficulty has been experienced in finding and retaining Air Force professionals with the necessary capability and interest to pursue an effective PM R&D program for maintenance. Such professionals are necessary, for either an in-house or contractor program.

Few contractors have had extensive experience or expertise in this area. Any contractual effort, to be effective, must be very carefully planned and closely monitored. I would anticipate that much of the first year's effort by a new contractor will be expended in a learning experience for his people and will not be too productive for the PM technology. Unless continued follow-on work is given such a contractor, his expertise is soon lost. During Fiscal Years 1969, 1970, and 1971 a total of $239K in exploratory development funds was obtained by AFHRL/AS for the development and tryout of PM and symbolic substitutes. The contractor personnel for this effort developed considerable expertise in working with PM for maintenance but they are no longer with the original contractor. The principal investigator, Dr. Edgar L. Shriver, is now president of his own firm, but his two PM assistants are no longer with him. Any successful program in this PM area must be a long range program making use of existing expertise and aimed at expanding such expertise. "Off again, on again" efforts, and/or jumping to a new contractor with every start will result in little improvement in PM technology.

8. During JTPT and symbolic test development efforts, several attempts were made to share the use of operational hardware on a noninterference basis. These experiences have indicated that no matter how cooperative the personnel of the operational unit, such time-sharing efforts are very expensive in terms of wasted man-hours of highly paid R&D professional personnel. For successful results, the necessary hardware must be assigned to the R&D project.

9. One of the persistent problems concerning the administration of PM has been getting maintenance supervisors to shed their supervisory role and assume the role of a disinterested test administrator. Because of their strong urge to show and help test subjects, most of these people have extreme difficulty in keeping themselves out of the actual tasks performance.

10. Timewise, it certainly would be impossible to administer a PM to a maintenance man for every possible task that his hardware system might produce. This world of tasks and people must be sampled. The model PM described previously provides a sampling procedure based on major task functions such as checkout, align, adjust, troubleshoot, etc. But even this sampling across possible tasks resulted in 48 tests and 133 scorable products. It would be impractical to give any one test subject all of these 48 tests at any one time. Systematic sampling schemes must be developed across tests.

The purposes for which PM results are to be used should be considered when developing sampling schemes. Such purposes of PM could include ascertaining (a) the job task proficiency of an individual, (b) the job effectiveness of a training program, and (c) the proficiency of a maintenance unit. Each of these purposes would require a different mix or mixes of tests and people. Some suggestions for such samplings can be found in AFHRL-TR-74-57(II) Part I (Shriver & Foley, 1974a). But it should be remembered that these are suggestions that must still be field tested.

In the case of determining unit proficiency, some PM can be administered by on-line observation of tasks that are often repeated such as checkout. There will always be a requirement for offline PM concerning critical, but seldom performed tasks. Whether the PM is performed on-line or off-line, the test administrator must use the same objective scoring procedures, the criteria of success being acceptable *products*.

11. The potential cost of PM in both training and field environments has certainly been increased by the proliferation of hardware subsystems (especially electronic) since the early 1960's. Over this period the state-of-the-art has been constantly changing. This has resulted in the proliferation of many variations in tasks for any one task function. For example, the alignment function produces considerably different tasks from hardware to hardware. Some long range actions are being taken to reduce the number of hardware having the same functional use. Because of the large numbers and types of maintenance tasks, a realistic system of priorities must be established for PM development. PM concerning the use of general test equipment would probably have the most immediate and widespread effect on the quality of maintenance. This development should be followed by PM for systems and subsystems having long life expectancies and large numbers in the field.

12. Current military grading systems must be modified to properly reflect the results obtained from PM and symbolic substitutes. In my opinion, the only adequate device for presenting such results is a profile similar to that shown in Figure 6. No attempt should be made to convert the content of such a profile into a single numerical score. The results of PM should never be combined with paper-and-pencil test results.

Institutionalization of New Technologies

Getting newly developed technologies such as PM institutionalized is a perennial problem, especially, when a technology requires fundamental changes in long existing programs, procedures, and attitudes of entrenched establishments. AFHRL/AS has been involved in the implementation of several well-developed and documented technologies, such as job performance aids and instructional systems design (ISD) including programmed instruction and job (task) oriented training. These experiences have indicated that it is extremely difficult to maintain the integrity of a technology during its so-called implementation. Operational organizations invariably attempt to implement a much "watered down" version of the technology and consequently obtain greatly "watered down" results. In some cases only cosmetic changes to existing programs are reported as implementations. Currently it requires years of persistent effort on the part of the research community to get a technology properly institutionalized.

A mechanism must be developed for the timely institutionalization of each new technology which will ensure its integrity. A mechanism for the orderly implementation of technologies similar to that used for new weapons systems is recommended. Such a mechanism must make efficient and effective use of the "know-how" of the developers of the technology and make them responsible and accountable for its implementation. A new technology should not be turned over to a using command for its operation until it is in place, "debugged" and operational–just as a new weapons system is not turned over to an operational command until it has been "debugged" and proven to be ready for operational use.

VI. PROPOSED PM R&D EFFORTS FOR MAINTENANCE

Excessive maintenance costs are never going to be reduced as long as we don't have JTPT and/or empirically valid symbolic substitutes to ascertain how efficiently maintenance men perform the *tasks* of their jobs. In my opinion, the lack of such measures of maintenance performance is a most serious *deficiency* in DOD. As such, R&D in this area should have an extremely high priority.

Areas for R&D Concentration

For a long range R&D effort, five general areas of concentration are recommended; namely, JTPT and matching symbolic substitute tests for electronic maintenance, JTPT and matching symbolic substitute tests for mechanical maintenance, and aptitude tests based on PM. The development and field tryout of a JTPT must precede the development of its symbolic substitute. The work on JTPT batteries for both electronic and mechanical maintenance should be started as soon as possible. The work on aptitude tests should not be started until JTPT batteries and the symbolic substitute tests have been completely field tested. More information concerning these areas of concentration follows:

1. *Refinement of Model JTPT Battery (Electronic Maintenance).* The already available model JTPT Battery (Shriver et al., 1975) should be given a large scale *field* tryout. (The AB328X4 Avionics Inertial and Radar Navigation Systems Specialist Course, which includes the AN/APN-147 and the AN/ASN-35, does not emphasize the mastery of job tasks. The tasks specific tests of this battery cannot be used in the formal course.) One thrust of this effort should be to further refine the

battery including its administrative procedures. A second thrust should be the development of sampling strategies which would be appropriate for determining the effectiveness of training programs and both individual and unit proficiency as discussed earlier under PM problems. This effort would require approximately two professional man-years *plus* the use of maintenance specialists as test administrators from the appropriate maintenance specialties. If it is necessary to select a system other than the AN/APN-147-AN/ASN-35 combination, this work would require approximately four professional man-years.

2. *Refinement of Symbolic Substitutes (Electronic Maintenance).* As previously indicated, a number of symbolic substitutes for JTPT were developed and given a limited tryout. Table 3 indicated that some of the symbolic tests show promising empirical validity. These promising symbolic tests must be more thoroughly refined and validated. In addition, further exploratory development is required for symbolic substitute tests for troubleshooting tasks in keeping with recommendations made in AFHRL-TR-74-57(III) (Shriver & Foley, 1974b). This effort would require between three and four professional man-years *plus* the use of maintenance specialists as test administrators and test subjects from the appropriate maintenance specialties.

3. *Development of Model JTPT Battery (Mechanical Maintenance).* A model JTPT battery similar to the model battery for electronic maintenance described previously should be developed for a typical mechanical subsystem such as a jet engine or tank engine covering both the organizational and intermediate levels of maintenance. This model should be thoroughly field tested. Sampling strategies as indicated for the electronic battery should also be developed. This effort will require approximately four professional man-years *plus* the use of maintenance men from the appropriate maintenance specialties as test administrators and test subjects.

4. *Development of Symbolic Substitutes (Mechanical Maintenance).* An attempt should be made to develop symbolic substitute tests with high empirical validity after the model JTPT battery is available for mechanical maintenance. The same contractor should develop these symbolics that developed the JTPT battery. A very rough estimate for accomplishing this symbolic effort would be four professional man-years.

5. *Job Aptitude Test Research Based on Results on JTPT.* R&D plans should be made to utilize the results of JTPT and symbolic substitute tests for standardizing military aptitude indices obtained from the Armed Service Vocational Aptitude Battery (ASVAB). *As a first step*, the military aptitude scores of all tests subjects used for the tryouts in the proposed JTPT R&D should be recorded. In addition, such aptitude scores should be obtained during any school or field administration of JTPT or symbolic substitutes. When sufficient data are obtained, the degree of relationship between JTPT results and various aptitude indices should be obtained. *Later*, when a sufficient number of JTPT are used in the field, a formal R&D project should be initiated to modify the ASVAB to directly reflect job success as measured by JTPT.

R&D Strategy. Probably the most cost-effective approach for PM for both electronic and mechanical maintenance would be to concentrate on the development and refinement of JTPT on use of key test equipments prior to proceeding with the other task functions of the proposed model test batteries. As indicated in Figure 5, the use of general test equipment is a prerequisite to maintenance task functions such as alignment, calibration and troubleshooting. In addition, general test equipments usually have wide usage in such task functions across many hardware systems and there are substantial amounts of data which indicate that many maintenance men are weak in their test equipment ability. So, a general improvement in ability to use test equipment is an important and necessary factor for the general improvement of several maintenance task functions. I would strongly recommend, therefore, that the early concentration for the proposed model test batteries be in JTPT concerning the use of key test equipments. Each PM development for a test equipment should be accompanied by the development of a programmed training package with sufficient practice frames for teaching the mastery of all its functions. Basic models of such training packages for 12 general test equipments are now available (see Scott & Joyce, 1975a through 1975 l). However, more practice frames should be included in these programs.

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