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Technical Report 502

A METHODOLOGY FOR ESTIMATING RELATIVE COST-BENEFITS OF ALTERNATIVE PRETESTING PROCEDURES

Jack H. Hiller

ARI FIELD UNIT AT PRESIDIO OF MONTEREY, CALIFORNIA

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saved (or lost) by pretesting could be estimated. A limited sample of empirical data was gathered and analyzed by applying these cost-benefit models. It was shown how these cost-benefit models can be employed to identify the best procedure in a specified set of competing procedures

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Technical Report 502

**A METHODOLOGY FOR ESTIMATING RELATIVE
COST-BENEFITS OF ALTERNATIVE
PRETESTING PROCEDURES**

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FOREWORD

The Presidio of Monterey Field Unit has conducted a broad program of research on problems of training in Army field units since its establishment in 1974. This program has resulted in a number of cost effective solutions to Army training problems in a number of different areas. The Unit Training Programs Team concentrates on issues relating to efficient use of training resources, integration of individual and collective training and the development and execution of cost effective training programs by units.

Current training doctrine in units as embodied in the Battalion Training Management System, directs trainers to conduct proficiency testing before individual or collective training is executed (i.e., pretesting). However, pretesting is rarely conducted in the field, and trainers typically challenge the cost effectiveness of such a procedure as a prerequisite for individual skill training.

This report describes a methodology that was developed for determining the cost-effectiveness of any form of pretesting procedure. The methodology was tested through its application to empirical data and found to be workable. The report describes how this methodology can be employed to improve the efficient use of time and resources for unit training through pretesting. The methodology can be easily used by training managers in FORSCOM, USAREUR, and other organizations responsible for conducting training.


JOSEPH ZEIDNER
Technical Director

A METHODOLOGY FOR ESTIMATING RELATIVE COST-BENEFITS OF ALTERNATIVE PRETESTING PROCEDURES

EXECUTIVE SUMMARY

Requirement:

To develop a quantitatively based methodology which will enable objective selection of an optimally effective pretesting procedure from a set of alternative procedures.

Procedure:

The research was accomplished as follows: Alternative pretesting procedures were formulated. Variables that affect the amount of time saved or lost by employing pretests were identified and defined. Algebraic cost/benefit models which take into account measurement accuracy, pretesting time, and training time were constructed so that the amount of time saved (or lost) by pretesting could be estimated. A limited sample of empirical data was gathered and analyzed to illustrate the possible applications of the cost/benefit models.

Findings:

It was found possible to construct generalized algebraic models that can be used to calculate the time saved or lost (i.e., a benefit value) when any particular pretesting procedure is employed in a group training situation. By simple comparison of the benefit values for each of the alternative procedures, an optimal procedure can be identified. Analysis of a small sample of data for infantry tasks implied that considerable improvements in time utilization may be achieved through use of carefully designed pretesting procedures.

Utilization of Findings:

This cost/benefit methodology will be used to identify an optimal pretesting procedure for the common tasks required by MOS 11B at Skill Level 1. Based on the logic of the cost/benefit analysis, and the preliminary empirical results, the use of pretesting, where appropriate, is being advocated by the Army Training Board.

A METHODOLOGY FOR ESTIMATING RELATIVE COST-BENEFITS OF
ALTERNATIVE PRETESTING PROCEDURES

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A METHODOLOGY FOR ESTIMATING RELATIVE COST-BENEFITS OF
ALTERNATIVE PRETESTING PROCEDURES

INTRODUCTION

The costs of education and training are one of the largest and most visible aspects of both civilian and military budgets. In the press to economize, the U.S. Army has been searching for methods which may achieve increased training efficiency as well as higher standards of effectiveness. One recently adopted feature of Army training doctrine aims at both efficiency and effectiveness. Specifically, this feature is the requirement to conduct performance-based diagnostic testing before training on a task is given, i.e., pretesting.

In theory, pretesting should yield the following advantages:

- a. Training time will be effectively gained by eliminating unnecessary training sessions.
- b. Planning and scheduling of training will be facilitated when pretests are used to identify common deficiencies;
- c. Testing (and training) standards will be maintained at high levels when the pretests are performance-based (i.e., actually performing a task instead of talking or writing about it);
- d. Infrequently used skills will be reinforced by the practice gotten from taking the performance-based pretests;
- e. Job climate will be improved by avoiding unnecessary, boring training.

The purpose of the research reported here was to develop a methodology for estimating the time savings produced by various forms of pretesting so that the most cost-effective form could be identified.

Pretesting has been incorporated into an on-the-job training system for infantry currently undergoing research and development by the Army Research Institute (Bialek et al., 1978). In this experimental system, the rifle squad leader is designated as the key trainer, and it is his responsibility to conduct the pretests. However, the amount of time that may actually be saved by having squad leaders conduct pretests is uncertain.

Consider the following hypothetical situation. A squad leader with a nine-man group intends to have all of his men become proficient in performing some individual task. It happens that he has insufficient information concerning any of his men's ability to perform the task, so he conducts a pretest. The pretest chosen is a performance test that may be administered to only one man at a time and it requires about 10 minutes to conduct for each man. Altogether then, conducting this pretest for the entire squad consumes 1½ hours of the trainer's time, and during this period the squad members may not be spending their time usefully. If it turned out that every squad member failed the pretest and needed substantial training, then no time was saved, and 1½ hours were lost.

Given that pretesting may not necessarily yield time savings and that different forms of pretesting may also differ in their cost-effectiveness, a need becomes evident for research to develop a methodology for measuring and predicting the cost-effectiveness of alternative pretesting procedures (including the procedure which deletes pretesting of any kind, i.e., the null pretest) so that an optimal procedure may be selected for a given situation. The research that was performed to meet this need will be described according to the following stages:

- a. Alternative pretesting procedures were designed.
- b. Variables which may affect the time saved or lost by employing the pretesting procedures (including the null pretest) were identified.
- c. Cost-benefit models were formulated in terms of training time saved or lost.
- d. An efficient data collection procedure was devised.
- e. The cost-benefit models were applied to sample data.

Each of these stages is described below.

DESIGN OF ALTERNATIVE PRETESTING PROCEDURES

The following procedures were considered for possible use as pretests:

- a. Each squad member estimates his own task proficiency;
- b. The squad leader estimates the task proficiency of his squad's members;
- c. Paper-pencil criterion-referenced tests are used;
- d. Computer or equipment intensive simulation is used for testing;
- e. Hands-on performance testing is used.

Self-estimates, although of uncertain validity, are fast and easy to acquire. Given the high levels of turbulence found in operational units, the infrequent occurrence of many infantry tasks, and the fallibility of memory, estimation by the trainer (i.e., squad leader) was rejected for this research effort. Paper-pencil tests are relatively quick and easy to administer, but have uncertain validity for infantry troops due to their verbal requirements. Simulated testing was rejected due to resource requirements beyond the scope of this project. Hands-on performance testing is typically time consuming, especially for process testing which requires observation of each task step. However, the results of performance testing provide the criterion measure of task proficiency for all practical purposes. In summary, a decision was made to explore the use of self-estimation, paper-and-pencil criterion-referenced tests, and performance tests.

One possible approach to using the three candidate pretests would be to employ each one by itself. For example, a soldier could be asked if he is able to perform a task to standard, and then either be placed in training if he said "no," or assigned to some other activity if he said "yes." Another possible approach is to arrange the candidate pretests in a systematic order to capitalize on their virtues while minimizing the effects of their weaknesses. Figure 1 shows an ordering of the pretests which may provide an optimal procedure. This procedure provides the easiest and fastest pretest as the first step, the second easiest to administer as the second step, and the most accurate, but time consuming, pretest (the hands-on performance test) as the last step for anyone who is not already eliminated.

Requiring soldiers to take the performance test as the last step insures that no one will falsely be considered proficient, since the soldier must demonstrate his proficiency before being credited with a "Go." Theoretically, the only error that can be made with the above ordering of pretests is to assign a soldier to training when he does not need it. Such errors may occur either because the soldier misjudges his true ability, or because he fails the paper-and-pencil test.

In addition to the pretesting procedure shown in Figure 1, several other possible procedures were defined for this research. These were:

- a. Self-estimate followed by performance test (see Figure 2);
- b. Paper-and-pencil test followed by performance test (see Figure 3);
- c. Performance test alone (see Figure 4);
- d. No pretesting, everyone enters training.

COST-BENEFIT ANALYSIS MODEL FOR SQUAD MEMBER TIME

Having defined alternative pretesting procedures, it is necessary to devise a method for identifying an optimal pretesting procedure for various training situations. The approach taken was to identify variables which may influence time saved or lost when squad members are pretested, and then to construct an algebraic equation which may be used to calculate the time saved or lost by using the diagnostic information produced by testing. In addition to the time saved or lost for the squad's members, the use of pretesting may also affect the time available to the squad's leader. However, since squad leader time has a different value than squad member time, and since there are approximately 10 times more squad members, the cost-benefits of pretesting for each kind of soldier will be dealt with separately. In the following portions of this paper, the cost-benefit analysis for squad member time will be developed, after which the analyses for the squad leader will be presented.

It should be stressed that the analysis presented below reflects the requirement that a soldier must be performance tested before he can be classified "GO." As a consequence, the only testing error is to classify a GO soldier NO GO during a pretest. Assuming the performance test is accurately scored, a NO GO soldier will not be misclassified GO.

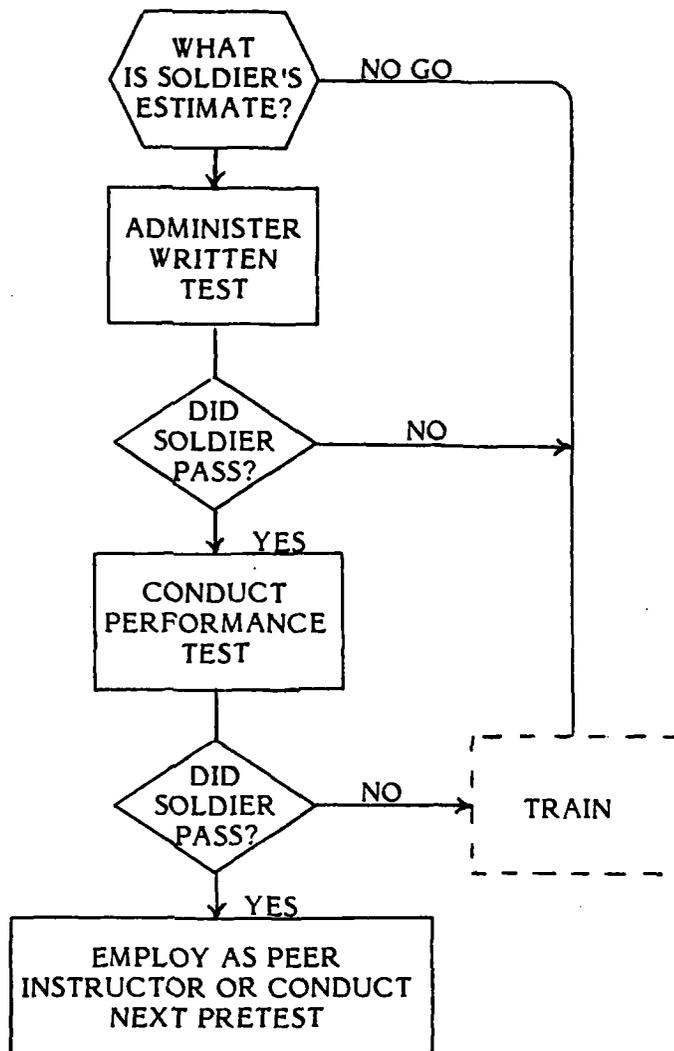


FIGURE 1
PRETESTING PROCEDURE A

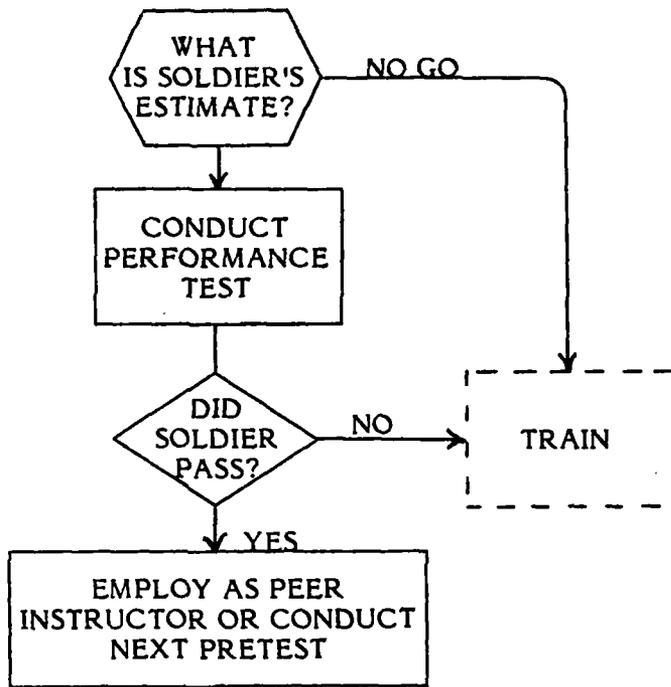


FIGURE 2
PRETESTING PROCEDURE B

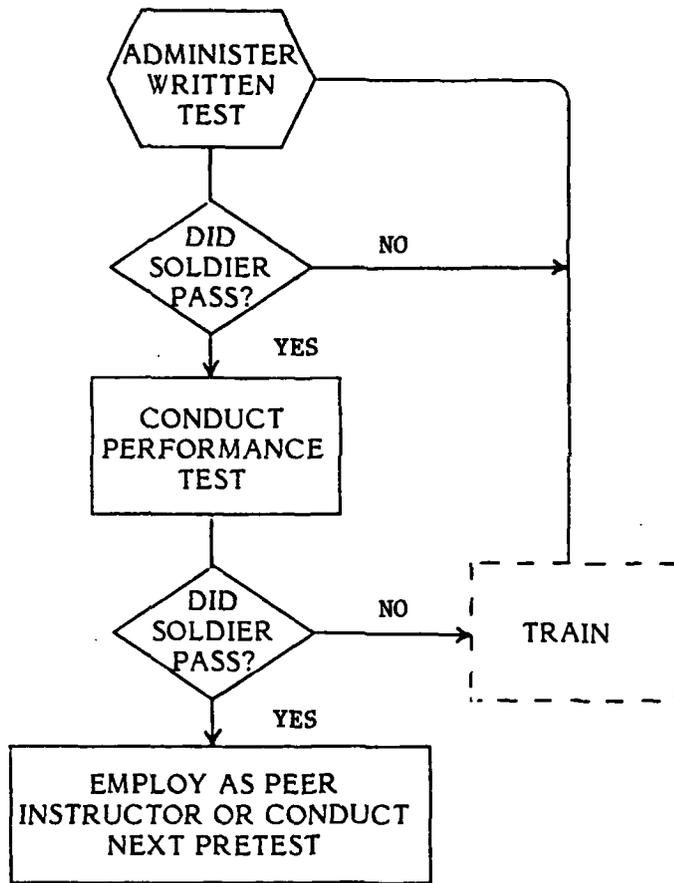


FIGURE 3
PRETESTING PROCEDURE C

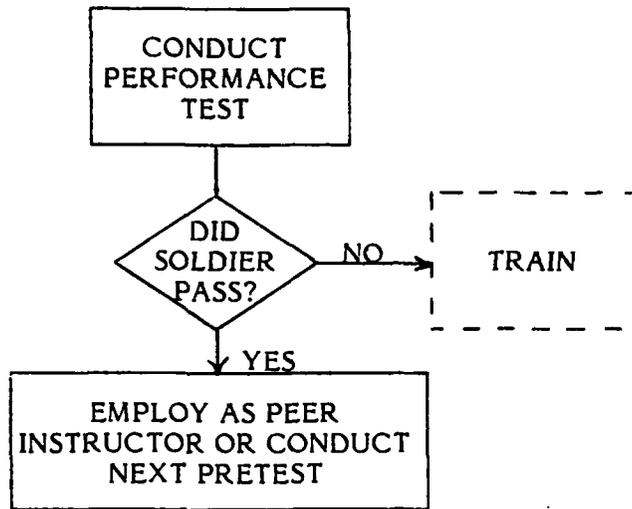


FIGURE 4
PRETESTING PROCEDURE D

The training model underlying the analysis is as follows:

1. A pretest of some sort is given (although for certain tasks, safety considerations rule out pretesting).
2. For most tasks to be taught, a complete, uninterrupted demonstration of the task is given; then each task step is in turn shown and explained--step by step. Where practical, the trainees follow along, performing each step.
3. The trainees then attempt to perform the task, with coaching available; trainers are to stop the trainee whenever he makes a mistake, and show/explain so that errors are not trained, but only correct skills.
4. Whenever the trainee or trainer believes the trainee has "learned" to perform the task to standard, a performance test for the record is given (training records are kept to aid training management decisions). If the trainee fails, his errors are corrected, and depending on the level of performance he is either retested, or looped back to step 3 to continue practicing.

Pretesting Variables:

The key variables that have been employed to perform a cost-benefit analysis of pretesting are defined below:

- B = Benefit, defined as the total number of man-minutes saved by applying any pretesting procedure.
- g = The proportion of squad members (excluding the squad leader who serves as the trainer/tester) who are able to perform the task (i.e., who are "GO") before training is given.
- e_N = The proportion of men in a squad who are able to perform the task but are erroneously classified by a pretesting procedure as "NO GO."
- $h = g - e_N$ = The proportion of men in a squad who are correctly classified by a pretesting procedure as "GO" on a task (hits).
- P = The time that it takes for an entire squad to be pretested.
- C = The time it takes for one soldier to undergo a performance test which is termed a "checkout."
- D = Time for the demonstration/explanation phase of training. The demonstration is a complete uninterrupted task performance. The explanation consists of a step-by-step demonstration with each step explained.
- N = The number of men in a given squad (excluding the squad leader who serves as the trainer/tester).

Primary Time Saved by Pretesting. The principle segment of time that may be saved by conducting a pretest is the time that it takes to demonstrate and explain how a given task is performed (D). Soldiers who are found by a pretest to be proficient in a task do not have to watch the demonstration/explanation, but may instead engage in a more productive activity, such as serving the trainer as a peer instructor or demonstrator, or working on another task, or taking care of a personal need.

For the purpose of constructing a model describing how time is saved or lost for squad members, it is assumed here that any soldier may take a performance test immediately after the task demonstration is finished. (This assumption is clearly consistent with the envisioned training system but represents a worst case situation for estimating the positive value of pretesting, since in reality, soldiers may have to wait to be tested while the squad leader coaches soldiers who need help.) In this case, the length of the demonstration (D) determines the amount of time that can be saved by an accurate pretest. The time that the pretest costs will be dealt with later.

Assume for the sake of argument that two soldiers who could both perform a task had to sit through a demonstration because a pretest was not given, or it was given but falsely found them to be "NO GO's." Each soldier would have lost D time. In addition to the D time lost for each soldier, it may be seen that the second soldier to be tested after the demonstration has finished has also lost the time that it took for the first soldier to be performance tested immediately after the demonstration. This time loss that is incurred as one or more soldiers wait for their turn to be tested occurs in the same way for both pretesting and posttesting. We have accordingly adjusted the time cost of pretesting when constructing the cost-benefit model, and will explain how after the pretest cost is defined below.

Algebraically, the total amount of time in man-minutes that is saved by having proficient soldiers avoid a demonstration that they do not need is found by multiplying the demonstration time, D, times the total number of men in a given squad who have been correctly classified as "GO" by the pretest, Nh, or finally:

$$\text{Primary Savings} = NhD$$

Pretesting Cost. The direct time cost for pretesting is simply the span of time that it takes the squad leader or trainer to pretest his entire squad, times the number of men in the squad, or:

$$\text{Uncorrected Pretest Cost} = -NP$$

Adjustment of Pretest Cost. In the new training system that underlies the analysis being developed here, a performance test must be administered to each soldier to establish if he is "GO" or not when the soldier or his trainer believes he has mastered the task. In other words, a performance test, called a checkout, must be administered to each soldier as part of the training procedure in the new system. Thus, the cost of the performance portion of the pretest procedure for a soldier who passes it is not uniquely attributable to the pretest procedure. The reason is this cost would have been incurred anyway when the performance test was given after the task demonstration. Therefore, the time cost for successful performance of the checkout during the

pretest procedure is deducted from the overall cost of the pretest procedure. The analysis of this time credit is explained below.

The number of men in a squad who are correctly measured to be "GO" on a task is defined above as Nh.

The time cost in man-minutes when one member of this group is administered the checkout, C, is the time C multiplied by the group size, Nh, since everyone in this group is held up while the trainer administers the checkout to one man. This time cost is:

$$CNh$$

Since each member of this "GO" group must take the performance test, the total time involved in man-minutes is found by multiplying the group size by the cost for administering one checkout:

$$ChCNh, \text{ or } CN^2h^2.$$

Thus, the cost of pretesting, adjusted for the posttraining checkouts that would have been given even if pretesting were not accomplished is:

$$\text{Pretest Cost} = -(NP - CN^2h^2), \text{ or } -N9P - NCh^2).$$

Time Lost When a Pretest Fails To Identify a "GO" Soldier. When a proficient soldier is misclassified as "NO GO" by a pretest, for whatever reason, he will then be required to attend a task demonstration/explanation session that he does not need. By spending his time on the unnecessary demonstration, other tasks which could have been attended to go undone, and thus time in this sense is wasted.

It might be argued that the time spent on the demonstration is not entirely wasted, since the proficient soldier's ability to perform well and to retain his skill are incremented to some degree. However, there are several reasons for believing that any such increment is generally negligible. These reasons derive from considerations of motivation and cognitive theory. A soldier who perceives that he already knows how to perform a task that is being demonstrated is not likely to watch closely, if at all. Rather, he may experience dissatisfaction and boredom, with consequent inattention and day-dreaming. From a learning theory point of view, the relatively passive demonstration/explanation session has a serious limitation--the cognitive requirements for watching someone else do something are different from those for actively, smoothly performing a task, so that transfer of learning from watching to doing is problematical; furthermore, this problem will be compounded by inattention.

The proportion of squad members who are mistakenly classified as "NO GO" is $\frac{1}{N}$ so that the total number of soldiers involved is Ne_N . The time wasted by providing these soldiers with the demonstration they do not need is simply:

$$\text{Wasted Time} = -Ne_N D.$$

Complete Cost-Benefit Model. Collecting the terms established above for:

- a. The primary time savings from pretesting;
- b. The cost of pretesting adjusted for the checkouts that would be given anyway; and
- c. The time wasted when a pretest fails to identify proficient soldiers, we have:

$$B = NhD - N(P - NCh^2) - Ne_N D$$

By factoring out "N," and rearranging terms we get:

$$\text{General Cost-Benefit Model: } B = N(D(h - e_N) - P + NCh^2)$$

SPECIFIC COST-BENEFIT MODELS

Having constructed a generalized benefit model, the next step is to derive a specific form of the equation for each of the specified alternative pretesting procedures.

Equation for Procedure A (Figure 1)

Procedure A involves all three pretest elements--self-estimate, written test, and checkout. It is necessary to define the following new variables to account for these elements.

y = The proportion of squad members who say, "Yes, I can perform the task to standard."

A = The time it takes a squad to be asked for their self-estimates plus the time to give the squad leader the answers.

w = The proportion of squad members who pass the written test.

K = The time it takes to administer and score the written knowledge test for a squad.

Two forms of the benefit equation need to be defined to reflect two possible outcomes for the self-estimates.

a. Equation for Procedure A Where y = 0. The time cost, P, involves only the time it takes to obtain the self-estimate. Since the checkout will not be given to any squad member, no possible "GO" members can be identified. Therefore h = 0.

Substituting A for P, and 0 for h yields:

$$\text{For } y = 0, B = N(D(0 - e_N) - A + NC0) = N(-De_N - A)$$

Inspection of this equation reveals the following points:

1. The benefit value cannot be positive since both terms are negative.
2. The least costly outcome is the case where the error term is zero (i.e., all soldiers correctly estimated that they couldn't perform the task) in which case the only cost stems from A.

b. Equation for Procedure A Where $y > 0$. The time required for pre-testing, P, has three components, one for each of the three pretest elements:

$$P = A + K + NwC$$

The term K mainly reflects the time that it takes for the slowest squad member to take the written test, where scoring is quickly done with a key or from memory. The term NwC reflects the number of squad members who have passed the written test, Nw, multiplied by the time required to give each one the checkout, C.

Substitution for P in the general model yields:

$$\text{For } y > 0, B = N(d(h - e_N) - (A + K + NwC) + NCh^2).$$

Equation for Procedure B (Figure 2)

The term P has two components--one for the self-estimate, A, and one for the time that it takes to give the checkout to each soldier who estimated he could perform the task, NyC. Substitution for P yields:

$$B = N(D(h - e_N) - (A + NyC) + NCh^2).$$

It may be observed here that acquisition of positive values for h is crucial for generating positive values for B. If h is zero (which may occur when no one can perform a task before training, or none of the soldiers who can perform the task estimate they can do it) then NCh^2 drops out, and the remaining terms cannot rise above zero. In addition, the largest possible benefits arise when the demonstration time is large, as well as h equaling one.

Equation for Procedure C (Figure 3)

The term P has two components, one for K and one for C. Substituting for P yields:

$$B = N(D(h - e_N) - (K + NwC) + NCh^2).$$

Equation for Procedure D (Figure 4)

The value for P is derived solely from the size of the squad and the time for conducting each squad member's checkout:

$$B = N(D(h - e_N) - NC + NCh^2), \text{ or}$$

$$N(D(h - e_N) - NC(1 - h^2)).$$

Equation for No Pretest

When no pretest is given, P is zero. Furthermore, there is no possibility of identifying any proficient soldier before the demonstration is given, so the proportion of hits, h, is zero.

The resultant equation is:

$$B = -NDe_N.$$

An equivalent alternative equation is based on the fact that the magnitude of the error term e_N equals the proportion of squad members who are "GO," g, before the demonstration is given. The alternative equation is:

$$B = -NDg.$$

Therefore, when no pretest is given no time can be saved, and time is lost as a direct function of the length of the demonstration/explanation and the number of soldiers who are proficient without further training.

Modification to the Equations for Simultaneous Checkouts

Performance testing for the majority of tasks covered by the new training system requires observation of the step-by-step process used by each soldier, since there is no clear-cut product. In some cases, even where evaluation of a product would suffice for a checkout, the value of the diagnostic information that may be gotten from observation of performance is so high that a process test is preferred. However, when a product-oriented test is preferred, then the cost/benefit equations need to be modified.

The definition for "checkout" used thus far assumed that only one soldier could be tested at a time. If a product test is employed, then it may be possible, where resources are sufficient, to test all squad members simultaneously, just as when a written knowledge test is used. Wherever a time cost for the checkout was previously involved, the cost was calculated by multiplying the number of test takers by C. However, for a simultaneously given product test, the cost is the amount of time that represents the upper bound of the slowest acceptable test performance.

As before, we term the time taken by the entire pretest as P. However, in formulating the credit adjustment for passing a checkout in the pretest that would have cost time after the demonstration, a change must be made. In this case the time cost of the checkout at either time is simply the proficient group size (i.e., Nh) multiplied by C. To avoid possible confusion, the checkout time for a simultaneous test is denoted C'.

$$\text{Pretest Cost} = -(NP - NhC').$$

The corresponding general model is:

$$B = NhD - NP + NhC' - Ne_N D, \text{ or } N(D(h - e_N) - P + hC').$$

AN EFFICIENT DATA COLLECTION PROCEDURE

The alternative pretesting procedures described above need to be comparatively evaluated from the standpoint of their cost-effectiveness. To do this, a task domain must first be specified, as for example the 56 common or basic tasks included in the Soldier's Manual for Military Occupational Specialty (MOS) 11B10. Given the fact that a data collection effort involving the four different pretesting procedures when applied to 11B tasks would be time-consuming and difficult to accomplish, it seemed important to devise an efficient data collection procedure. The solution adopted was as follows. Participating soldiers are asked to read a description of the task, conditions, and standards for each task that is sampled from the Soldier's Manual. Each soldier is then asked first to estimate his ability to perform it, second to take a paper-and-pencil test regardless of his estimate, and finally to take the performance test regardless of his written test result. The full procedure is explained in advance so that soldiers who might otherwise overestimate their capability realize that a hands-on performance test will be given. The data collected by this procedure may then be distributed to all four active pretesting alternatives by means of a logic tree analysis, thereby effecting a sizeable economy in data collection requirements. The analytical technique is illustrated by the results for a sample task in Figures 5 through 8.

ILLUSTRATIVE APPLICATION OF THE COST-BENEFIT MODEL

Reported here is a description of an application of the general cost-benefit model to the four alternative pretesting procedures that have been described earlier in this paper in Figures 1 through 4. In addition, the model is applied to the procedure of placing all soldiers into training without pretesting. This application is based on data that were collected from infantry soldiers in units of the 7th Infantry Division at Fort Ord, Calif., during 1977. The data were specifically collected on a sample of five Soldier's Manual tasks included in the set for Military Occupational Specialty (MOS) 11B. These five tasks were selected for study because they provide a sample which covers a fairly wide spectrum of activities--leadership skills (Organize, and Employ a Tank Hunter-Killer Team), cognitive (Encode/Decode, and Authenticate Messages with a KAL 16 Coding Device), and "hands-on" (Emplace/Recover an M16A1 Anti-Personnel Mine). This small sample of tasks clearly cannot be used to estimate accurately possible results for all tasks in the 11B series, but it does serve as a test bed.

The data were collected according to the procedure described in the previous section. Values for all variables except A (the time to obtain self-estimates) are shown in Table 1; the value for A was approximately 1 minute. The logic tree analysis was used to obtain the values for model-specific variables for a hypothetical squad having nine members in addition to the leader.

By employing the sample data shown in Table 1 to the alternative pretesting procedures, it is possible to generate the benefit values in minutes for each of the sample tasks, as shown in Table 2.

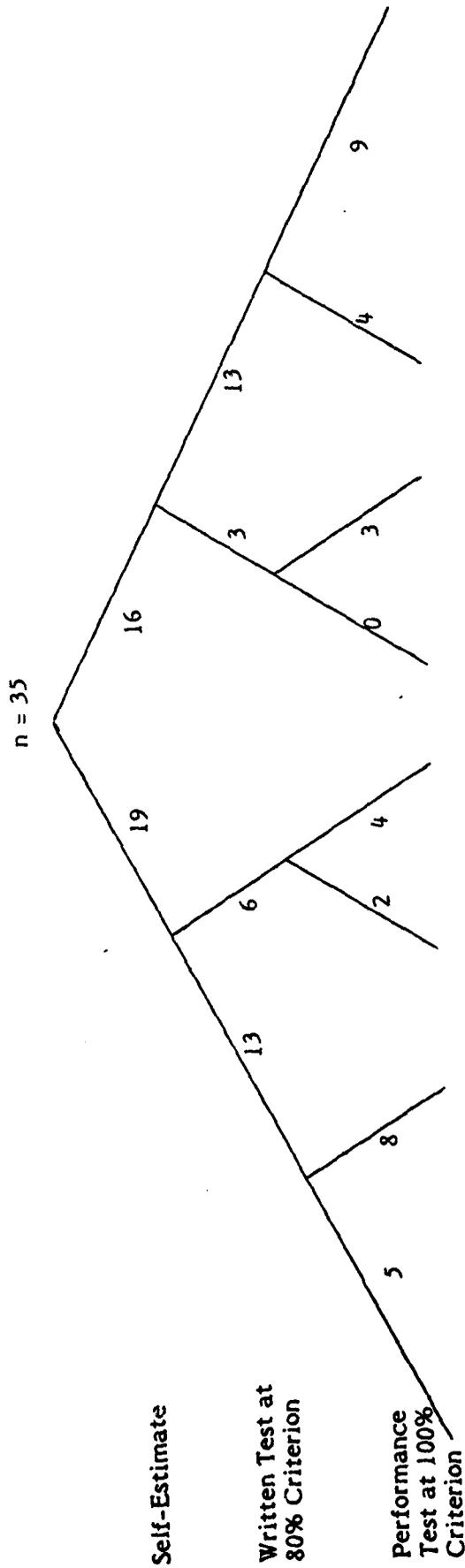


FIGURE 5

Data collected for the Soldier's Manual Task -- Encode/Decode KAL61. The paths to the reader's left (l) are used for Go results and to the right (r) for No Go results. Thus, 5 soldiers passed all pretests and 9 passed none.

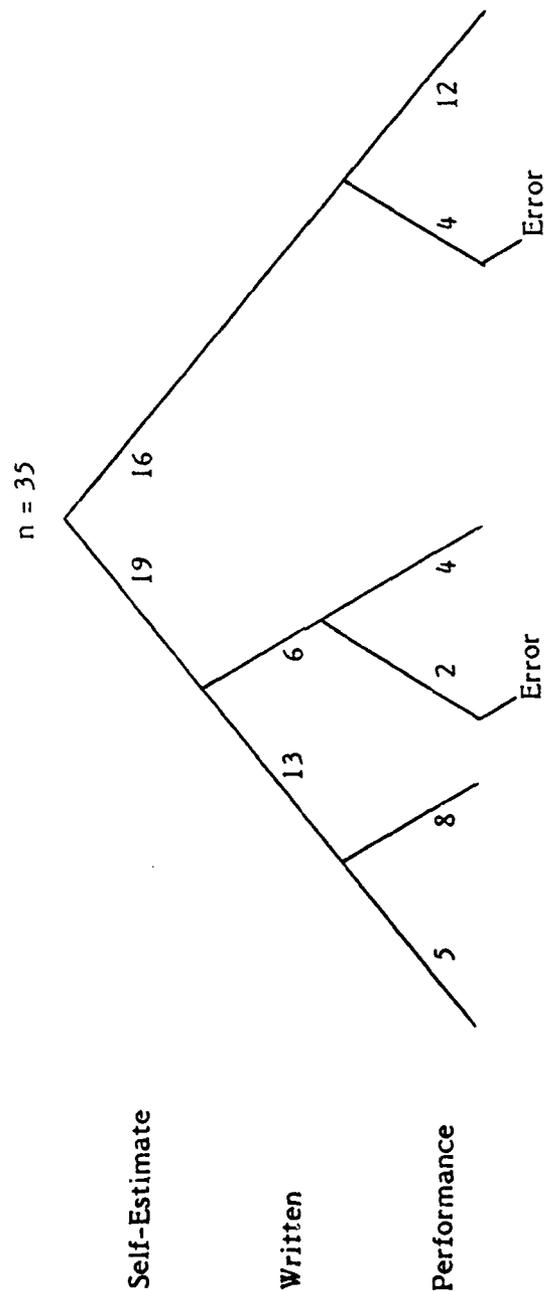


FIGURE 6

Results for task -- Encode/Decode KAL61 -- needed to calculate the benefit value for Procedure A.

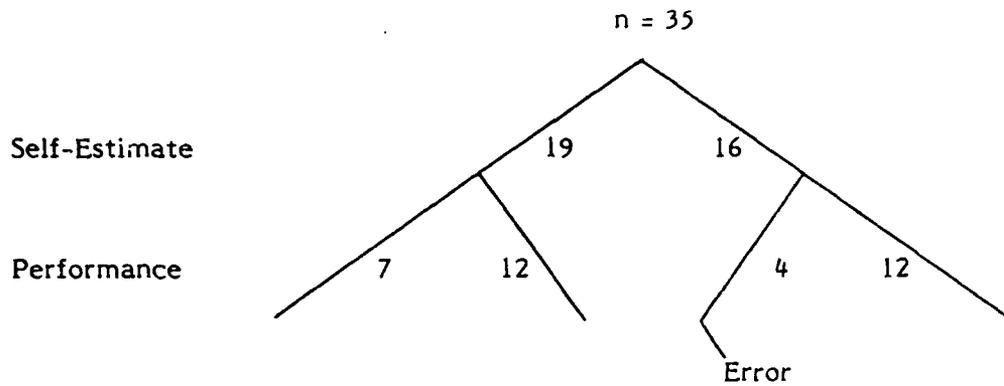


FIGURE 7

Results for task -- Encode/Decide KAL61 -- needed to calculate the benefit value for Procedure B.

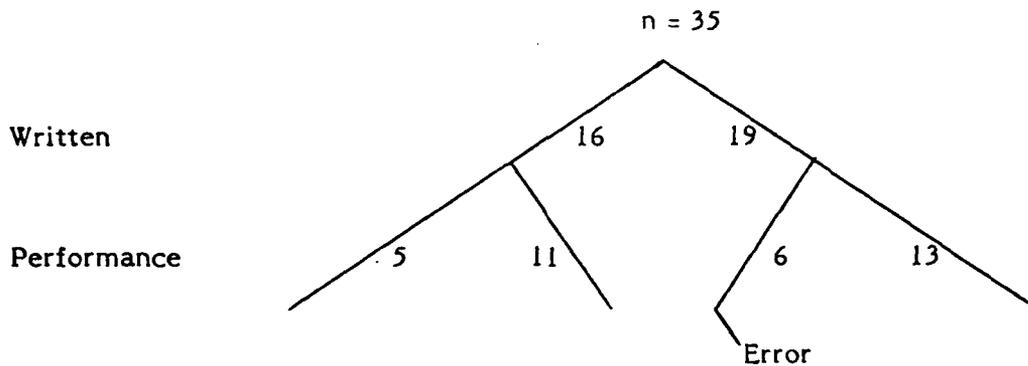


FIGURE 8

Results for task -- Encode/Decode KAL61 -- needed to calculate the benefit value for Procedure C.

TABLE I

Empirically Based Data for Procedures Permitting False "NO GO" Classifications

Task	MODEL SPECIFIC VARIABLES																		
	FIXED VARIABLES			PROCEDURE A ASK SOLDIER				PROCEDURE B ASK SOLDIER				PROCEDURE C PAPER-PENCIL TEST	PROCEDURE D HANDS ON TEST		PROCEDURE E NO PRETEST				
	D	g	C	e _N	y	K	w	P	e _N	y	P	e _N	K	w	P	e _N	P	e _N	
Organize Tank	15	32	.67	3.3	.07	.67	5.0	.60	24.0	.00	.67	21	.07	5.0	.88	31	0	.67	0
Hunter Killer Team	14	36	.71	7.0	.21	.79	5.0	.50	38.0	.00	.79	51	.21	5.0	.64	45	0	.71	0
Employ Tank	36	28	.28	6.1	.28	.48	8.0	.00	09.0	.17	.48	27	.28	8.0	.03	10	0	.28	0
Hunter Killer Team	35	31	.31	3.2	.17	.56	3.4	.37	15.0	.11	.56	17	.17	3.4	.46	17	0	.31	0
Emplace and Recover	36	21	.53	1.0	.28	.61	1.0	.44	06.0	.19	.61	7	.22	1.0	.53	6	0	.53	0
M16A1 AP Mine	30	50	.50	4.1	.20	.62	4.5	.38	18.4	.09	.62	25	.19	4.5	.49	22	0	.50	0
KAL 61	6	20	.20	2.4	.09	.12	2.6	.23	12.9	.09	.12	17	.08	2.6	.29	16	0	.20	0
Encode/Decode																			
KAL 61																			
Authenticate																			
\bar{x}																			
s																			

Note. D = Time it takes to demonstrate how to perform a task.
 g = Proportion of squad members who are able to perform the task before training is given.
 C = Time spent to administer a performance test to an individual.
 e_N = Proportion of squad incorrectly classified by a pretest as "NO GO".
 y = Proportion of squad members who say they are "GO" before training.
 K = Time to administer and score the written test for all squad members.
 w = Proportion achieving 80% or higher on the written test.
 P = Time to administer the pretesting procedure to an entire hypothetical nine-man squad.

TABLE 2
BENEFIT VALUES IN MINUTES FOR 9 MAN SQUADS

Task	Procedure A Ask Soldier Paper-Pencil Test, Hands- On Test	Procedure B Ask Soldier Hands-On Test	Procedure C Paper-Pencil Test, Hands- On Test	Procedure D Hands-On Test	Procedure E No Pretest
Organize Tank Hunter Killer Team	34.5	125	- 31.4	45.7	-193
Employ Hunter Killer Team	-102	58.9	-172	- 51.1	-230
Emplace and Recover M16A1 AP Mine	-152	-255	-157	-384	- 70.6
KAL 61 Encode/Decode	-139	-119	-153	-148	- 86.5
KAL 61 Authenticate	- 54.3	- 20.7	- 27.2	41.9	-100
\bar{x}	- 82.6	- 42.2	-108	- 99.1	-136

It may be seen from the summary line for Table 2 that Procedure B minimized the time lost (i.e., it appears to be the most cost-effective procedure), while automatically placing all soldiers into training appeared to be the most costly procedure. Procedure B happens to be the pretesting procedure selected by the new training system, but, of course, the data reported here are insufficient to establish the validity of this selection. With a sufficiently large sample of tasks, the kind of raw data shown in Table 2 could be analyzed by a one-way analysis of variance test to estimate if the alternative procedures reliably differ, and, if so, then analyzed by a test like the Newman-Keuls to estimate exactly which procedures are distinctly different in their benefit values.

A COST-BENEFIT ANALYSIS FOR SQUAD LEADER (TRAINER) TIME

Conducting a pretest obviously consumes the squad leader's own time as well as the squad member's time. In this section, cost-benefit models for the squad leader's time in his role of trainer/tester are developed.

The time that a pretest, P , takes is a cost for the trainer which needs to be adjusted for the checkout time, C , that would be consumed anyway after the demonstration/explanation even if a pretest weren't given. The adjustment is simply the number of hits, Nh , multiplied by the time for each checkout. The tentative benefit equation for the squad leader is:

$$B_L = -(P - NhC).$$

In the relatively unusual case where all squad members are hits, then the time that would have been spent on the demonstration, D , is saved. The appropriate equation is:

$$B_{LD} = -(P - NhC) + D.$$

Given the infrequent applicability of this model, it will not be discussed further here.

Since the squad leader's actions affect all of his men, it may be appropriate to weight his time by the number of his men, N . The benefit equation then becomes:

$$B_{WL} = -N(P - NhC).$$

The specific formulation of B_{WL} for each of the alternative pretest procedures simply requires substituting for P the expressions previously explained. The equations for each procedure are as follows:

$$\begin{aligned} \text{Procedure A, } y > 0: \quad B_{WL} &= -N(A + K + NwC - NhC), \text{ or} \\ & -N(A + K + NC(w - h)) \end{aligned}$$

Procedure B: $B_{WL} = -N(A + NyC - NhC)$, or
 $-N(A + NC(y - h))$

Procedure C: $B_{WL} = -N(K + NwC - NhC)$, or
 $-N(K + NC(w - h))$

Procedure D: $B_{WL} = -N(NC - NhC)$, or
 $-N^2C(1 - h)$

Procedure E, No Pretest: $B_{WL} = 0$.

To illustrate the behavior of B_{WL} , the data from Table 1 have been used to generate results, which are shown in Table 3. It can be seen from these results that the least costly procedure is of course to skip the pretest. Conversely, the data show that the most expensive procedure would be to give all squad members a checkout.

The experimental training system places a strong emphasis on the use of peer trainers to motivate acquisition of specific task and leader skills by squad members, and to increase the squad leader's ability to spend his time where he can be most productive. Therefore, it is possible that squad leaders may generally assign one of their squad's members who has passed a pretest to conduct the task demonstration. In this case, the previously defined model for B_{LD} applies, since the time that the demonstration takes is saved by the squad leader. Table 4 displays sample weighted squad leader benefit values for B_{WLD} where the general equation is:

$$B_{WLD} = -N(P - NhC) + D.$$

The actual application of this equation to infantry squads for tasks with relatively short demonstration times may well be limited by the squad leader's desire to provide supervision. However, it is apparent from the sample B_{WLD} values shown in Table 4 that rather dramatic time savings for the squad leader may be generated by his use of peer instructors.

In the next section, various benefit models are constructed by combining the benefit equations for squad member and squad leader time.

COMBINED BENEFIT MODELS FOR THE SQUAD LEADER AND HIS MEN

A combined general equation for B and B_{WL} is:

$$B + B_{WL} = N(D(h - e_N) - P + NCh^2 - P + NCh), \text{ or } N(D(h - e_N) - 2P + NCh(h + 1)).$$

TABLE 3
 B_{WL} BENEFIT VALUES FOR TRAINER TIME IN MINUTES

Task	Procedure A	Procedure B	Procedure C	Procedure D	Procedure E
Organize Tank Hunter Killer Team	- 54	- 9.0	-120	- 88.2	0
Employ Tank Hunter Killer Team	- 54	- 54.4	-124	-164	0
Emplace and Recover MI6A1 AP Mine	- 81	-192	- 86.8	-356	0
KAL 61 Encode/Decode	- 99.2	-102	-114	-179	0
KAL 61 Authenticate	- 33.4	- 30.9	- 26.8	- 38.1	0
\bar{x}	- 64.3	- 77.7	- 94.3	-165	0

TABLE 4
 B_{WLD} BENEFIT VALUES FOR TRAINER TIME IN MINUTES

Task	Procedure A	Procedure B	Procedure C	Procedure D	Procedure E
Organize Tank Hunter Killer Team	234	279	168	200	0
Organize Tank Hunter Killer Team	234	279	168	200	0
Emplace and Recover M16A1 AP Mine	171	60	265	104	0
KAL 61 Encode/Decode	180	177	165	100	0
KAL 61 Authenticate	156	158	162	151	0
\bar{x}	202	189	172	101	0

Since the overall terms which reduce P (to reflect checkouts that would have been given after the demonstration even if the pretest were not used) constitute only a fraction of P, this combined model provides a less favorable outlook for pretesting.

The specific equations for each of the experimental alternative pretesting procedures are presented below:

Procedure A, for $y > 0$:

$$B + B_{WL} = N(D(h - e_N) - 2(A + K + Nwc) + Nch(h + 1))$$

Procedure B:

$$B + B_{WL} = N(D(he_N) - 2(A + NyC) + Nch(h + 1))$$

Procedure C:

$$B + B_{WL} = N(D(he_N) - 2(K + Nwc) + Nch(h + 1))$$

Procedure D:

$$B + B_{WL} = N(D(h - e_N) + NC(-2 + h^2 + h))$$

Procedure E: $B + B_{WL} = 0$.

The corresponding equations for $(B + B_{WLD})$ are found simply by adding ND to the $(B + B_{WL})$ values for Procedures A, B, C, and D.

For certain possible applications of this scheme of analysis, it may be thought inappropriate to be giving the trainer's time a weight equal to the trainee group size. For example, if the trainer and trainees are working full time at training, then multiplying the trainer's pretesting time cost by the trainee group size may lead to an awkward result. Consider that when the pretesting benefit for the squad members is calculated, the time that the pretest takes is multiplied by the group size, N. Now when B_{WL} is calculated, the pretest time is also multiplied by N. In this way, when B and B_{WL} are combined, the benefit (or cost) of the pretest time for the group is effectively counted twice. Therefore, unweighted equations for B_L and B_{LD} may also be desirable for some situations. The combined general equation for $B_L + B$ is:

$$B + B_L = N(D(h - e_N) - P + NCh^2) - P + NCh, \text{ or}$$

$$N(D(h - e_N) - P(N + 1)/N + Ch(Nh + 1))$$

The equation for $B_{LD} + B$ is:

$$B + B_{LD} = N(D(h e_N) - P + NCh^2) - P + Nch + D, \text{ or}$$

$$N(D(h - e_N) - P(N + 1)/N + ch(Nh + 1)) + D.$$

To conveniently illustrate the relative behavior of all benefit models, the sample data from Table 1 have been used to generate results (i.e., mean benefit values, and rank ordered scores for the means from each model) which are shown in Table 5. It may be seen that Procedure B gave the best overall performance ($\bar{x} = 4$ man-minutes saved) and Procedure E the worst ($\bar{x} = -76$ man-minutes, lost).

If the sample data were reliable, then the following conclusions could be made for the infantry tasks that were studied. When only the squad leader's time and not squad member time is considered, and when the squad leader will either conduct or supervise the task demonstration (Models B_L and B_{WL}), then no pretesting should be given. But, for all seven remaining models, Procedure B ranks first five times and second twice. However, these conclusions are meant only to illustrate how the models behave and may be analyzed, but cannot be regarded as reliable because of the small samples of tasks, soldiers, and testing locations.

CONCLUSIONS

A methodology designed to enable selection of an optimally efficient pretesting procedure for use in group training/testing situations has been explained and illustrated with sample results. This methodology consists of:

- a. A generalized set of benefit models,
- b. Specified alternative pretesting procedures,
- c. Specific algebraic equations which permit calculation and comparison of the benefits accruing from the various alternative procedures,
- d. A suggested efficient data collection plan for the specified alternative pretesting procedures.

One salient limitation of the specified alternative pretesting procedures and their benefit models derives from an ideal requirement imbedded in the proposed on-the-job infantry training system underlying this research--namely, the requirement that task training may officially terminate for a soldier only when he has demonstrated task proficiency by passing a performance test. As a consequence of this requirement, all analyses were predicated on the assumption that no soldier would falsely be classified proficient by a pretest. This point is illustrated by the diagram below, where the validity of both pretest outcomes is described as a function of the soldier's true proficiency:

TABLE 5
MEAN AND RANK ORDER BENEFIT VALUES FOR ALL MODELS AND PROCEDURES

Model	Procedure A	Procedure B	Procedure C	Procedure D	Procedure E
B	- 83	- 42	-108	- 99	-136
B _L	2	1	4	3	5
B _{WL}	- 7	- 9	- 10	- 18	0
B _{LD}	2	3	4	5	1
B _{WLD}	- 64	- 78	- 94	-165	0
B _L	22	21	19	11	0
B _{LD}	1	2	3	4	5
B _{WLD}	202	189	172	101	0
B+B _L	- 90	- 51	-118	-117	-136
B+B _{WL}	-147	-120	-202	-264	-136
B+B _{LD}	- 61	- 21	- 89	- 88	-136
B+B _{WLD}	119	147	64	2	-136
\bar{x} Mean	- 12	4	- 41	- 71	- 76
\bar{x} R.O.	2.1	1.7	3.7	4	3.8

NOTE: L refers to the model for the squad leader/trainer; W to weighting the model; and D to the substitution of a peer trainer for the squad leader in the demonstration.

		PRETEST OUTCOME	
		GO	NO GO
TRAINEE'S TASK PROFICIENCY	GO	VALID A	INVALID B
	NO GO	INVALID C	VALID D

All pretesting procedures were constructed so that cell C could not occur; the only mistakes logically possible stem from cell B. However, the ideal requirement that training always be capped with a performance test is sometimes perceived as a time-consuming luxury when training is conducted by operational units in field settings. Thus in reality, the invalid outcome depicted by cell C may sometimes occur. It is necessary therefore to perform an additional analysis which will enable estimation of the costs or benefits that arise when performance testing is not reliably practiced in a training system and the required research is underway.

A final point to consider is the potential scope of application offered by the quantitative approach toward cost-benefit analysis presented here. Although only time costs have been discussed, financial costs may also be handled.

Time may be directly translated into money by multiplying it by the rate of pay. Once time is translated into dollars, then other financial costs may be introduced into the benefit equations. For example, if expensive simulation equipment needs to be purchased, then its amortized cost may be included in the cost-benefit equation which represents the appropriate alternative pretesting (or testing) procedure. Another example concerns the use of expensive ammunition which will be expended during performance testing.

The potential annual dollar equivalent of the time that the Army may gain by the use of pretests can be illustrated with an example from infantry training. There are a minimum of 56 basic, common infantry tasks that any soldier in a rifle or weapons squad must be able to perform. It is reasonable to assume that each squad would be required to train on each of the 56 tasks at least once a year. The mean benefit values shown in Table 5 may be multiplied by 56 to estimate the time involved for a single squad in 1 year, and then multiplied by the number of squads in the Army. Finally, the time involved for squad leaders and members may be multiplied by their estimated hourly costs to find the dollar equivalent. As an example of the annual benefit that may be achievable, the results for Procedure B may be compared with Procedure E using the benefit model $B + B_{LD}$. In this comparison, Procedure B was found to gain about 430,000 man-hours which has a value of approximately 6.5 million dollars, based on salary costs for productive training time (estimated at 30% of paid time by Bialek, 1977).

More important than the annual dollar differences between the various pretesting procedures is the percentage of time that may be freed or lost, given that combat readiness depends on the amount of training time that can be used. A comparison of Procedure B with Procedure E for Model B shows the

difference between the mean benefit values to have been (-42-(-136)), or 94 minutes. For a single squad member this amounted to 94/9, or about 10 minutes. If the average time for task training (i.e., task demonstration, plus skill practice until mastery is achieved, plus the checkout) were 1 hour, then the time saved by Procedure B over Procedure E would have been about 17%. Thus if the magnitude of this sample result is accurate, then training efficiency and effectiveness may be significantly enhanced by application of this quantitative approach toward estimating pretesting costs and benefits.

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