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ARI Research Note 87-59

# A REVIEW OF MODELS OF COST AND TRAINING EFFECTIVENESS ANALYSIS (CTEA)
## Volume II: Cost Analysis

Arvil V. Adams and Margaret Rayhawk
The Consortium of Washington Area Universities

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for

Contracting Officer's Representative
John J. Kessler

Training and Simulation Technical Area
Robert J. Seidel

TRAINING RESEARCH LABORATORY
Jack H. Hiller, Director

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Cost and training effectivenes must be considered jointly in considering how to meet training requirements. Cost predictions for various training alternatives are not at their most valuable in the early stages of a weapon system's life-cycle, and this report discusses the problems encountered with data availability at this stage. A cost model must incorporate economic concepts as opposed to purely accounting costs. The economic ideas embedded in CTEA are discussed, and the search for, and difficulties in developing and applying, a generic CTEA model are addressed.

Finally, building on earlier reviews, 17 cost models and guidebooks are examined in terms of purpose of development, features included, usefulness in the early stages of weapon system development, and strengths and weaknesses of the model or guidebook. In a summary on the lessons to be learned, the more advanced state of training effectiveness development is noted; suggestions are made for new research on costing; continued early coordination between system designer, training developer, and cost analyst is advocated; and comparison-based (OVER)

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methods are recommended as one means to address data problems in the early stages of system development.

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## FOREWORD

One of the missions of the Army Research Institute for the Behavioral and Social Sciences (ARI) is to conduct research and development in individual training methods. The Army has established the Training Technology Field Activities (TTFA) to determine how and where training technology can be used to provide cost-effective military training . TTFAs are located at several Army schools and are organized as partnerships consisting of ARI, the Training and Doctrine Command (TRADOC), and the particular school. This report is part of ARI's support of the TTFAs.

The task to develop a theoretical model which would enable TTFAs to systematically compare alternative ways of training on combined cost and effectiveness variables was contracted to the Consortium of Universities of the Washington Metropolitan Area and monitored by ARI. The contract with the Consortium is one of a series let by ARI intended to bring the expertise of academia to bear on the Army's personnel research and also support the Defense Department's effort to strengthen the university research base.

The products of this contract are four reports, two which review pertinent literature and two which treat the development of the theoretical model. Anyone concerned with cost and training effectiveness analysis or the requirements of model development will find these reports comprehensive and thorough.

## ACKNOWLEDGMENTS

This report was prepared with support from the Consortium of Washington Area Universities and the Army Research Institute for the Behavioral and Social Sciences. We are indebted to a number of individuals who have made important contributions to the study. We wish to especially thank the Army Research Institute Advisory Committee, including D. Bruce Bell, Stanley F. Bolin, Hyder Lakhani, and John J. Kessler, who offered advice and counsel throughout the study and who served as a constant sounding board for our ideas. A special note of appreciation is offered to John J. Kessler who served as the Contracting Officer's Representative. Dr. Kessler provided valuable assistance throughout the effort and made many useful suggestions for improving the final report.

During the course of the study, several individuals at the Ft. Knox Armor Center provided us with access to specialized literature and insights into the conduct of training using computer-assisted instruction, training devices, and simulators. These insights have enriched the study enormously. Among others who contributed in this respect, we want to especially thank John A. Boldovici, Don F. Haggard, and Don M. Kristiansen. From our own staff, we wish to thank Eileen McKeon for her assistance in the production of this report. As is customary, the views expressed in this study are our own and do not necessarily reflect the official views of the U.S. Army. We naturally assume responsibility for any errors or omissions.

Arvil V. Adams
Margaret L. Rayhawk

A REVIEW OF MODELS OF COST AND TRAINING EFFECTIVENESS ANALYSIS, VOLUME II: COST ANALYSIS


## EXECUTIVE SUMMARY

Requirement:

To identify cost and training effectiveness analysis (CTEA) models which might be adapted to the needs of the Army for improving its training development system, particularly in areas involved with use of new training technology. The focus of this report is on models that deal with training costs. The companion report, Volume I: Training Effectiveness Analysis, examines models concerned with measures of training effectiveness.

Procedure:

A body of literature asse-'led by the Army Research Institute and literature already in possession of the authors was searched. This literature enabled the devlopment of a keyword search of computerized data bases which included the Defense Technical Information Center (DTIC), the National Technical Information Service (NTIS), the Educational Resources Information Center (ERIC), and PsychScan. References were also obtained through contact with several training and cost experts and major consulting firms.

Findings:

The report provides the economic background and framework needed to understand and evaluate CTEA models. Seventeen models of potential applicability to training technology decisions are reviewed and analyzed. The major impediment to utilization of most models is seen as resulting from their inability to treat the costs of training development. Models which generate and process estimates based on experience with similar forms of training technology are considered useful tools.

Utilization of Findings:

This literature review will be valuable to researchers who need a grounding in CTEA models. It will also be of interest to decision-makers who wish to know something of the internal workings of a model and where the trade-offs reside. The authors are using the contents of this report to develop a CTEA model called Training and Cost Iterative Technique (TECIT) which will be described in subsequent publications.

CONTENTS

TABLES

# COST AND TRAINING EFFECTIVENESS ANALYSIS: A REVIEW OF LITERATURE ON COST MODELS

## I. INTRODUCTION

### THE PROBLEM

The fielding of new weapon systems and technologies in the nation's defense requires the training of those who will use them. The effectiveness of these systems and the success of new technologies depends to a large degree on investments in human capital alongside those in physical capital. The human element plays an important role in even the most capital intensive system affecting the capacity of the system to carry out its mission successfully. The design of a weapon system or technology can directly affect the size of investment in training required as well as the effectiveness of both when fielded. Overly complex technologies may introduce additional cost in training and diminish the effectiveness of these technologies when fielded. It is even possible for poorly designed systems to fail altogether due to the human element.

The Army, like other Services, has been aware of this relationship between man and systems. Over the past two decades, the Army has invested heavily in research to develop models of this relationship allowing it to predict cost and performance of new weapon systems and technologies as they relate to training and the human element. Cost and Training Effectiveness Analysis (CTEA) models developed for this purpose have been used in a wide variety of settings by the Army. Two problems have plagued the use of CTEA models. The first is the search for generic models which can be adapted to a full range of systems and technologies. Development to date has been concentrated on specific models intended for a limited range of applications. The second is the search for models which can be used in the early stages of development of a new system or technology to predict the success of alternative designs.

The earlier one can anticipate the cost and effectiveness of a design, the easier it is to adjust the design to address deficiencies leading to excessive cost and impediments to its effectiveness. Every weapon system and technology passes through a development life-cycle beginning with a conceptual stage and continuing through development, procurement, operations and maintenance stages. Design changes at later stages of the life-cycle, frequently requiring expensive retooling and retrofitting, can be avoided through early assessment of the impact a design will have on the human element of its operation. CTEA models, however, have encountered problems in the prediction of cost and training effectiveness during early stages of the life-cycle.

The problem is in part linked to the absence of historical data for evaluation of these issues, but also to appropriate prediction methodologies.

Recently, the Army established a new unit within its Training and Doctrine Command (TRADOC) charged with the improvement of training, particularly that involved with the use of new training technologies. The Army Training Technology Field Activities (TTFA's) are a joint effort of TRADOC, the Army Research Institute, and selected Army Schools to investigate the cost and effectiveness of new training technologies. Among these technologies is that of computer-based instruction. The TTFA's will employ CTEA models in their investigation.

## OBJECTIVES

To support this effort and the broader task of improving the Army's ability to predict the cost and effectiveness of new weapon systems and technologies early in their life-cycle, the Consortium of Washington Area Universities, represented by the University of the District of Columbia and the George Washington University, were assigned the task of developing a CTEA model oriented toward the needs of TTFA's, as well as other interested Army and Department of Defense organizations.

This report, prepared by the George Washington University, will focus on CTEA cost literature. A companion report, prepared by the University of the District of Columbia, will address the

CTEA training effectiveness literature. The objective is to identify models which might be adapted to the needs of TTFA's and to extract the lessons to be learned from the use of these models in other settings that could enhance their contribution to the TTFA's. This review will be followed in a second phase of study by the development of a CTEA model along with a validation plan for use by the TTFA's.

This review of CTEA cost literature builds on several earlier reviews of these models including those of Matlick et al (1984), Rosen et al (1981), and Knerr et al (1984). The report will emphasize new developments and issues in the literature which are determined to be relevant to the development of a predictive CTEA model serving the needs of TTFA's.

## APPROACH TO THE STUDY

The literature search began with a body of CTEA literature assembled by the Army Research Institute (ARI) and literature already in the possession of the authors. A review of this literature and its references led to the identification of other sources which appeared useful to our efforts. This literature also served as the means for developing a keyword search of computerized data bases spanning civilian and military literature. The data bases searched included the Defense Technical Information Center (DTIC), the National Technical Information Service (NTIS), the Educational Resources Information Center (ERIC), and PsychScan.

The search also included references obtained through contact with several training and cost experts and major consulting firms.

Using keywords focusing on training and cost effectiveness, the DTIC search yielded some 350 abstracts. ERIC and PsychScan identified approximately 250 references, while NTIS produced an additional 300 references. An examination of these abstracts for the relevance to the task at hand led to a narrowing of the number of studies actually reviewed. A bibliography of the literature reviewed is included with this report.

## ORGANIZATION OF THE REPORT

The report is organized in four sections. Section II, which follows, provides a lexicon of the methods and concepts used in developing cost estimates for CTEA. The section provides a framework for reviewing CTEA cost literature in Section III. The reader who is familiar with these methods and concepts will want to proceed to Section III. In Section III, 17 CTEA models and guidebooks are examined. The models and guidebooks are described and compared with respect to selected features. The analysis examines the purpose for which each model was developed and appraises its strengths and weaknesses for the purpose at hand. Section IV concludes with a summary of the lessons learned from the literature for the development of a CTEA cost model.

# II. METHODS AND CONCEPTS IN CTEA COST MODELS

## APPLICATIONS AND OBJECTIVES OF COST MODELS

Rational choice among alternative instructional delivery systems requires the consideration of cost alongside training effectiveness. It makes little sense to select the most effective system to satisfy a particular training requirement without regard to differences in cost. At the same time, selection of the least-cost alternative in the interest of cost savings or cost avoidance may result in an unacceptably low level of training effectiveness. Cost and training effectiveness, as such, must be considered jointly.

As suggested by Orlansky (1985), new training technology can be recommended for adoption when it is more effective than current technology and costs the same or less; or when it has about the same effectiveness but costs less than current technology. Where a trade-off between costs and effectiveness is present, the choice of an alternative might be preferable if much higher levels of effectiveness can be achieved with only slightly higher expenditures. By the same token, small reductions in effectiveness might be accepted when accompanied by large reductions in cost.

The development of a CTEA model formalizes the process of choosing among alternative training technologies by comparing the cost and training effectiveness of these systems. Within this framework, a cost model is employed to value the resources engaged in each system. The model requires the alternative systems be identified and their associated resources specified. It then provides an algorithm for determining the cost of these systems. The model, as such, provides rules for the conduct of the cost analysis and assures a systematic result for comparison. The model, as discussed below, may serve more than one objective which will influence its specification.

The resources engaged in alternative training technologies conventionally include facilities, equipment, instructional material, supplies, and personnel. The expenditure of these resources is calculated for each alternative over the life-cycle of a weapon system or technology. For training associated with a new weapon system, it is important that the CTEA and cost estimation take place as early in the system life-cycle as possible. The prediction of training cost as affected by the design of a weapon system is an important management tool for achieving system objectives. Changes in system design to control these costs and meet objectives can be undertaken at a lower cost in the early stages of a system life-cycle than in later stages.

## Cost Objectives

The cost to be measured at each stage of a system life-cycle will vary with the objectives of the analysis. Braby,et al (1975) point out that when the objective of the analysis is to select the least-cost alternative from among a specified set of training technologies, all of which are capable of meeting the training objectives, then the resources common to all alternatives can be factored out and ignored in the analysis. However, when the objective is to determine the absolute life-cycle cost of a system, then all resources must be included and valued at their opportunity cost.

The use of a cost model for CTEA requires that the objectives of the analysis be clearly specified. In most instances, the decision to provide training has already been made. The issue is how to provide the training in an effective and efficient manner. In this case, the factoring out of common resources among the alternatives and valuing the remainder is appropriate. However, if the decision is whether or not to offer training, then the cost of all resources over the life-cycle of a system should be compared with the benefits of the training. If the decision is to be based on a system's affordability, then budgetary cost may enter the picture.

Because of the different cost estimates resulting from these approaches, it is important that the objectives served by the cost model be clearly specified. Typically, the analyst will be confronted with a set of alternative training technologies, all of which have been determined acceptable. The problem in this instance is one of cost-minimization. Common resources among the alternatives can be factored out and the remainder valued. The output of the model may be expressed in forms related to unit cost, such as the average cost per graduate or the average cost per student position, or in terms of time and flows, such as the annual cost of operating a school for a specified number of students.

## Level of Cost Aggregation

The use of a cost model for CTEA also requires that the level of aggregation be specified for the analysis. An analyst may choose to partition the training into tasks and to produce cost estimates for each task and then sum these estimates to arrive at a total program cost. Alternatively, total program cost estimates may be produced directly. The latter may prove difficult, especially during the conceptual stage of a weapon system's development where the absence of hard information may introduce substantial uncertainty into the cost estimates. The identification of a task or tasks on fielded weapon systems whose characteristics are comparable to a task on the system to be developed may open the way to information reducing the level of uncertainty in the cost estimates at this key stage of the weapon system's life-cycle.

## Generic Cost Models

The search for a generic CTEA model, and by inference, a generic cost model is a theme found throughout the CTEA literature. The concept of a model for all seasons and circumstances is intuitively appealing, although difficult to obtain. The objective is to produce a model that can be used in cost estimation for training technologies varying from classroom lectures, to computer-based instruction, to simulators and other training devices. Moreover, the model should be flexible enough to produce cost estimates at any stage of a weapon system's life-cycle.

The goal of a systematic method for cost and training effectiveness evaluation suited to any situation is achievable at a cost in the level of user sophistication required to implement the model. Generic models by their very nature operate at a much higher level of abstraction than specific models. The enumeration of resources engaged in computer-based instruction, for example, would be more fully specified in a specific cost model than in a generic model. The latter would demand a higher level of user sophistication than the former. That is, the user must have a higher order of working familiarity with the training technology in order to implement a generic cost model. This tradeoff should be considered in the development of a CTEA model for the benefit of those expected to conduct the analysis.

## Location and Level of Training

Training for any weapon system or occupational specialty may take place in a variety of locations and levels which can produce special problems for the cost analyst. In many situations training will occur initially in a school setting followed by assignment to a unit where additional training will take place. Some of the training in each setting may be for the individual and some for the individual as part of a unit. The recognition of this is important to the proper specification of the cost model. A task oriented model, for example, may treat the training setting as a variable to determine the cost effectiveness of task training in alternative settings. Most cost models appear to focus on individual training in an institutional setting.

Admonitions and Model Limitations

In all choices, the analyst must keep in mind the applications and objectives of the CTEA exercise. These elements of the exercise must be clearly stated and understood by all to ensure the model is properly specified and to provide a means for the critical appraisal of its result. The analyst should also acknowledge the limitations of a cost model that merely sums the value of resources employed in a training program without relating these resources to a production function. The latter is necessary to the determination of optimal combinations of resources in achieving different levels of training output.

The conduct of cost modeling for CTEA involves both art and science. The economic concepts employed, described below, lend rigor to the process. The operationalizing of these concepts, however, is sometimes an art form. The choice of a discount rate, for example, or the measurement of an indirect cost frequently requires the analysts's judgment. In all instances, these judgments should be clearly identified. In general, the practice of sensitivity analysis is appropriate in cost modeling as in other exercises to determine the sensitivity of results to the analyst's assumptions.

## ECONOMIC CONCEPTS IN COST MODELING

### Opportunity Cost versus Accounting Cost

CTEA cost models place a value on the resources used by alternative training technologies. These resources are valued in terms of their opportunity cost, which may differ from their value in terms of accounting costs. The opportunity cost of a resource used in training is measured by valuing the goods or services the resource could be used to produce in its best alternative use. A classroom instructor training individuals in the techniques of repairing communications satellites, for example, might alternatively be employed full-time in the repair of these satellites. The opportunity cost of the time spent in the classroom, as such, is measured by the value of the foregone repair services.

Accounting costs will include direct payments for resources used, but unlike opportunity costs, will omit implicit payments. The accountant, for example, will treat the depreciation of a classroom building used for training as a direct cost in an accounting period, but will ignore the foregone income potential of the undepreciated portion of the building. The book value of undepreciated portion of the building, if it could be liquidated and the proceeds invested, would produce a stream of income during the accounting period. This foregone income is an implicit cost of keeping the building in service for future use and is not included by the accountant in the cost of training, but would be included in the opportunity cost.

Time and market conditions may also distort the relation between accounting and opportunity costs. Accounting costs for capital goods whose expected life extends beyond a single accounting period are a function of the historical cost of these goods and their expected life. Changing market conditions over the life of a capital good may change the value of this resource in its alternative uses and therefore its opportunity cost. The accounting cost would remain unchanged, however, fixed by the historical cost of the capital good and its expected life.

As an example, a classroom building built in one period would be valued by the accountant in terms of its historical cost and expected life. A depreciation schedule would be established based on this information. If conditions later changed such that no alternative uses for the building existed, the building's opportunity cost would become zero while its accounting cost would remain unchanged. Alternatively, if the market value of the building increased, its opportunity cost would also increase, but the accounting cost would remain unchanged.

## Sunk Costs

Costs that have already been incurred and cannot be recouped are referred to as sunk costs. Such costs should not be included in CTEA cost models. Training technologies that employ off-the-shelf technology provide an example of sunk cost. The Research & Development embedded in the off-the-shelf technology represents a cost that has been incurred, and in most instances, this cost cannot be recouped. As such, the R&D should be treated as a sunk cost and ignored. The key in this example is that the cost cannot be recouped. By contrast, however, the R&D required to develop a new device or other technology that cannot be bought off-the-shelf should be included in the system cost. The investment in this R&D could be diverted to alternative uses and is therefore not a sunk cost.

## Fixed and Variable Costs

CTEA cost models distinguish between fixed and variable costs. Fixed costs do not vary with the number of trainees or amount of training provided in a planning period. These costs are incurred regardless of how much training takes place during the period. This follows from the fact that the resources involved cannot be easily diverted to other uses during the planning period. They are, in fact, fixed resources. Depending on the length of the planning period, some resources, such as classroom space, may be fixed in supply. Constructing new classrooms or converting old ones to alternative uses cannot be done on short notice.

Other resources, however, can be varied during the planning period to affect the number of trainees or amount of training provided. The cost of these resources is considered a variable cost. Examples might include the number of instructors assigned to a school or the instructional materials provided. Fixed resources define the scale of training possible in any planning period. The number of special training devices provided, for example, or the number of classrooms constructed and the intensity of their use defines the upper limit of training possible during a planning period. Variable resources can be applied to these fixed resources to determine the amount of training done within this limit.

The scale of training possible can be expanded or contracted in subsequent planning periods by changing the stock of fixed resources used. In the long run, all resources become variable resources. Given long enough, it is possible to construct new classrooms or to convert existing classrooms to alternative uses. With enough time, additional training devices can be provided. In the short run, represented by a planning period, however, some resources will be treated as fixed and others as variable.

## Time Value of Money

The life-cycle cost of alternative training technologies will normally involve incurring different costs at different times. In order for two or more alternatives to be compared on an equal economic basis, CTEA cost models must consider the costs of each alternative currently or at their "present values." This recognizes that money has earning power over time. To find the present value of expected future costs, the technique of discounting is used. This technique determines the amount of money which, if invested today at a selected interest rate, would be sufficient to meet expected future costs.

Present value analysis normally will not be needed in evaluating alternatives that do not involve large capital expenditures and whose cash flows under each alternative occur at approximately the same times during the planning period. Where the timing of expenditures is significantly different, however, present value analysis should be used. When long-lived capital assets are to be government-owned or built to government specification, present value analysis is necessary to determine whether or not it is economical to incorporate features in the system that will cost more initially, but which will reduce future costs for operation, maintenance, repair, and improvements.

## Discount Rates

Although present value analysis is a generally accepted practice, selecting an appropriate interest rate for discounting in the analysis has been the subject of much controversy. Arguments have been presented for using the cost of borrowing by the Treasury to using the rate of return that can be earned in the private sector. The rate applied has a direct effect on the results of an analysis; therefore, the choice of a rate is very important. The present value of two training technologies, one with the cost up front and another with the cost deferred into the future, will differ sharply depending on the discount rate used.

A high discount rate reduces the cost in present value terms of a technology whose cost is deferred into the future. The higher the discount rate used, the more advantage given to deferred cost technologies in comparison with up-front cost technologies. OMB Circular A-94 requires executive agencies, including the Department of Defense, to use a 10 percent discount rate together with constant dollars for determining the present value of expenditures spread over time. The only exception is for water resource projects where a 7 percent discount rate is used.

Constant versus Current Dollars

Changes in the general price level will affect the purchasing power of the dollar. When the general price level is rising, the real value, or purchasing power of the dollar is falling. Conversely, when the level is falling, the real value of the dollar is rising. There are two basic approaches to dealing with price-level changes in cost studies. (1) Estimate future costs in today's prices; that is, in "constant dollars." (2) Estimate future costs at the anticipated price levels that will exist then; that is, in "current dollars."

Constant dollars are always associated with the purchasing power of the dollar in a base year. Estimates are in constant dollars when future costs are adjusted to exclude inflation so that they reflect the level of purchasing power in the base year. OMB Circular A-94 requires executive branch agencies to use constant dollars in their cost analyses.

Residual Value of Assets

The length of the planning period may exceed the expected life of some resources used in training requiring that these resources be replaced once, even several times during the training period. In other cases, however, the expected life of a resource may exceed the length of the planning period. At the end of the planning period the resource will have a residual value which should be subtracted from its cost. An example might be, once again, a classroom building or possibly a training device. To the extent a resource is not fully expended during the planning period, its cost should be adjusted to reflect this. CTEA cost models will consider the residual value of the resources used.

### Indirect Benefits

Some training technologies may have secondary effects which occur outside the organization that provides the training. An example of an indirect benefit, and one not normally considered in evaluating military training, is the worth of the training to the individual in preparing him or her for a civilian occupation. The value of this training in the broader social setting is normally not considered in the CTEA cost model since the benefit is not realized directly by the provider of the training. In some instances, however, the analyst may attempt to document indirect benefits and evaluate them outside the cost model.

## SUMMARY

An economic analysis is a critical step in the design of training systems. Following Braby (1975), a rational choice of an instructional delivery system cannot be based upon training effectiveness without regard to cost and vice versa. In order to facilitate the economic analysis of instructional delivery systems, a cost model must be constructed. This section has reviewed the applications and objectives of cost models for CTEA and the economic concepts employed therein. As such, it provides a framework for reviewing the CTEA cost literature in the section to follow.

# III. A REVIEW OF CTEA MODEL COST LITERATURE

## MODEL COMPARISON

Following an approach used by Rosen et al (1981), 17 CTEA cost models and guidebooks are compared in Table 1. The comparison includes an examination of how the various economic issues described above are addressed by CTEA cost models. Most of these models were developed for the Army. The comparison shows substantial variance in the treatment of inflation, discounting, and residual assets. Less than half could be used for cost prediction in the conceptual stage of weapon system deveopment. In the section which follows, each model and guidebook is examined in greater depth with respect to these and other features.

## REVIEW AND ASSESSMENT

This section reviews each CTEA cost model. The review traces the conceptual and methodological developments in CTEA cost modeling

TABLE 1 CTEA Cost Model Comparisons

| MODEL | Branch of Service | Date | Cost Elements Identified | Cost Algorithms Provided | Cost Predictive/ Conceptual Stage | Has Model Been Applied | Cost By Task | Cost By Training Program | Years in Planning Cycle | Inflation Factors Included? | Discount Factors Applied | Residual Assets Considered | Computer-ized |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Training Effectiveness Cost Effectiveness Prediction (TECEP) Braby et al | Navy | 4-75 | Yes | Yes | Yes | Yes | Possible | Yes | Indef | No | Yes | Yes | Yes |
| Training Efficiency Estimation Model(TEEM) Jorgensen et al | Army | 7-78 | Yes | Yes | Yes | Yes | Possible | Yes | Indef | No | Yes | Yes | Yes |
| Training Consonance Analysis (TCA) Hawley and Thomason | Army | 12-78 | Yes | No | Yes | Yes | Possible | Yes | 20 | Yes | Yes | Yes | Yes |
| Litton Mellonics Adaptation of TECEP Matlick et al | Army | 9-80 | Yes | Yes | Yes | Yes | Yes | Yes | Indef | No | Yes | Yes | Yes |
| TRADOC Systems Analysis TEA Handbook (TRASANA TEA) | Army | 1980 | Yes | No | No | Yes | No | Yes | Indef | Yes | Yes | Unknown | No |
| General Model/ Methodology for Conducting CTEA, Vector Research | Army | 1-76 | Yes | Yes | No | Unknown | No | No | Indef | No | No | No | No |
| Training Developers Decision Aid,Machine Ascendant MOS(TDDA/ MAMOS)Applied Science | Army | 1978 | Yes | Yes | No | No | Yes | Yes | Indef | No | No | No | Yes |
| Multiple Launch Rocket System Repairer CTEA (MLRSR) TRASANA TEA | Army | 1984 | Yes | Yes | No | Yes | No | Yes | 20 | Yes | Unknown | No | No |
| Comparison-Based Prediction of Cost-Effectiveness CBP, Klein Associates | Army | 6-85 | No | No | Yes | Yes | No | No | Unknown | No | No | No | No |
| Cost-Effectiveness Specification/Computer Based Training Systems Seidel and Wagner | DARPA | 1977 | Yes | Yes | No | Unknown | No | Yes | 15 | Yes | Yes | No | Yes |
| Computer-Based Job Skills Education Program(JSEP) Kraft | Army | 1983 | Developing | Developing | No | No | No | No | Indef | Unknown | Proposed | Proposed | Unknown |

TABLE 1. CTEA Cost Model Comparisons.

| MODEL | Branch of Service | Date | Cost Elements Identified | Cost Algorithms Provided | Cost Predictive/ Conceptual Stage | Has Model Been Applied? | Cost By Task | Cost by Training Program | Years in Planning Cycle | Inflation Factors Included | Discount Factors Applied | Residual Assets Considered | Computer-ized |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B-1 Systems Approach to Training (B-1 SAT) Calspan Corporation | Air Force | 7-75 | Yes | Yes | Yes | Unknown | No | Yes | 10 | Yes | Yes | Unknown | Yes |
| Methods of Designing Instructional Alternatives (MODIA) Rand Corporation | Air Force | 10-77 | Yes | Yes | No | Yes | No | Yes | 5 | Yes | Yes | Yes | Yes |
| DAIS Training Requirements Analysis Model (DAIS/TRAMOD)Dynamics Research Corporation | Air Force | 1978 | No | No | No | Unknown | Yes | Yes | Indef | Unknown | Unknown | Unknown | Yes |
| Coordinated Human Resources Technology (CHRT) Dynamics Research Corporation | Air Force | 1978 | No | Developing | No | Unknown | Yes | Yes | Indef | No | No | No | Yes |
| Manpower and Hardware Procurement (HARDMAN) Dynamics Research Corporation | Navy, Army | 1980, 1981 | Yes | Yes | No | Yes | No | Yes | Indef | Unknown | Unknown | Unknown | Yes |
| Training Development Decision Support System(TDDSS) Applied Science Associates | Army | 1981 | Yes | Yes | Yes | Yes | No | Yes | Indef | Unknown | Unknown | Unknown | Yes |

which have taken place since 1975. The features and issues examined include the following:

--the branch of service for which model was developed,

--the objectives of the model,

--the strengths and weaknesses of the model,

--the link established between cost and training effectiveness,

--the field testing of the cost model, if done, and

--the suitability of the model for CTEA cost prediction in the early development stage of a weapon system

<u>Training Effectiveness Cost Effectiveness Prediction, (TECEP)</u>

This technique for choosing cost-effective instructional delivery systems was developed for the Navy by Braby et al of the Training Analysis and Evaluation Group(TAEG) at the Naval Training Equipment Center in Orlando, Florida. This 1975 model was the capstone of several earlier TAEG efforts and contains refinements incorporated during a year of field trials. The TAEG group worked with, borrowed from, and synthesized much prior work of media selection experts,task category and learning guidance developers, and inter-service training designers. Matlick et al (1980a) describe the TECEP cost model as the most thorough application in the Life Cycle System Management System.

The resulting model is the foundation for much of the military cost and training effectiveness efforts of the last decade. As noted in Rosen et al (1981) and Knerr et al( 1984a), the Army and the Navy have incorporated this model into their Instructional System

Development (ISD) strategies. Knerr et al further note that it has been applied extensively since being incorporated in the military ISD model.

The model was developed to assist the skilled training system designer to make instructional delivery system choices during the conceptual design phase of a weapon system. The system designer identifies training objectives, and chooses two or more alternative instructional delivery systems capable of supporting the objectives. Estimating the costs of these alternative delivery systems is the next step in the TECEP process. The model is designed to develop training programs for institutional training.

The 37 cost elements in the TECEP model incorporate the cost of acquiring and operating facilities and equipment, the cost of supplies, the cost of the design of instructional material, and the cost of student and support personnel. Cost estimates are generated for each alternative and comparisons are made of the advantages and disadvantages of each system.

The cost elements are well-defined, the algorithm is easily understood,and at the time of its development the costing portion of the TECEP model was computerized using a FORTRAN IV program. This model was originally developed for the Navy and included naval data sources and references. It has since been modified for use with Army sources and references. The cost output of the TECEP procedure included the present value for each alternative, the total and average annual cost per student position, and the distribution of the incidence of costs over the life of each alternative. Other variables may now be in the output.

The TECEP model's emphasis is on cost minimization. It can be used to compare alternative training approaches. It is not intended to assess differential benefits or effectiveness for these approaches. The training approaches for which costs are estimated are not presented in any ranked order. The model cannot forecast total system cost.

The TECEP model requires access to multiple data sources, and there will be a variability in data reliability. This fact should be noted. It assumes all variable cost functions are linear -- an assumption that may not be tenable for specific training situations. The model does not provide any means for evaluating secondary or spillover effects. It assumes these effects to be constant for all alternatives.

The authors of TECEP provide some common sense considerations: (a) if an alternative involves a low cost per student graduate but a significant initial investment -- such as computer-assisted instruction -- it makes little sense to consider this technique unless resources appear in existing budgets (b) similarly, if courseware is to be locally developed, then skilled personnel, equipment, time and dollars must be available (c)if command policy or existing investment in production facilities would require significant change for the proposed alternatives, then these practical factors will outweigh any model-recommended alternatives.

As published, the cost elements for instructional material development would require modifications to accurately reflect the cost of computer-assisted instruction. If the analyst is required to provide cost by task, the model would need modification. The cost model is based on valid economic concepts.

As noted earlier, the TECEP model has been the basis for much of the training and cost evaluation in the services since 1975. Its authors recognize the limitations of the model in both its training and costing portions and note that testing is continuing. Its most significant contribution is as the seedbed for the training and cost models which have since evolved.

Training Efficiency Estimation Model,(TEEM):

This model was developed at the Army Research Institute by Jorgensen and Hoffer in 1978 as part of the continuing effort to refine training estimation during the conceptual stage of the weapon system development.

TEEM's unique contribution to military model evolution is in the development of a training efficiency ratio and the linking of that ratio to cost to provide cost effectiveness ratios as the basis for choice.

The methodology can be used at the earliest stages of weapon system development where the analyst is dealing with probable weapon characteristics from which are developed preliminary duty or task description lists. Matlick et al do not feel the ratio is strong but probably the "best available in an early CTEA" (1980,a,p.V-12). TEEM was developed for use in an institutional setting.

The model generates a variety of training programs combining different media and methods to meet the training needs of the preliminary task description. Generated along with other training programs is an ideal training program with no constraints to be used as the base case. The ideal training program and constrained training programs are quantified. An efficiency ratio is derived by dividing the constrained programs by the ideal. Efficiency here refers to the extent that task characteristics match training program characteristics. The efficiency ratio reflects the match between learning needs and the media and methods meeting those needs.

A decision metric is derived by dividing the cost of each alternative by its efficiency ratio. The costing is based on the TECEP cost model then in use for several Army training cost estimate efforts. The training efficiency ratio has since been modified to use actual equipment as the base case and to use an Army-modified TECEP cost model.

A significant advantage of the TEEM ratios is that they can be used to compare alternative training programs for a given weapon system as well as providing comparisons across weapon systems. Rosen et al (1981) consider the TEEM model highly useful since it is predictive of effectiveness, efficiency, and cost-effectiveness.

A drawback of the original model is the exclusion from consideration of such information as managerial constraints, personnel characteristics and teacher characteristics. The model also needed further testing to resolve the question of what weights should be applied to the cost factors.

Training Consonance Analysis,(TCA):

This model was designed for the Army Research Institute by Hawley and Thomason in 1978 to perform CTEA at the points required by the Life Cycle System Management Model. The authors further modified the TECEP and TEEM descriptions of tasks and media-method combinations to arrive at Training Consonance Ratios. The TCR is the sum of matches between the presence of a variable in a task description and in a medium-method combination divided by the number of variables in the task description.

For example, if 43 training consonances are scored and the task description includes 48 variables, then the ratio for that task is .896.

The methodology also uses training deficiency and training excess scores to remove inefficient training methods. The TCR can be used with the TECEP costing variables to provide cost-effective ratios. It is designed for institutional training projections.

In addition to providing Army-related performance data source suggestions, Hawley and Thomason provide important advice to the cost analyst to include in their cost data requests, at a minimum, (a) a description of training concepts which describes how training will be carried out and what instructional methods are to be employed (b) the make, model, quantity, and quality of materiel required (c) the quantity, grade, and skill level of personnel required and (d) time requirements and materiel usage data such as the length of course and supplies expended.

Another contribution to the costing methods developed earlier were their recommendations to project sunk costs, fixed costs, and variable costs for use in alternative comparisons. Hawley and Thomason advise that training resource costs be expressed in constant-year dollars and that DOD policy specifies that for that for CTEA the base cost year is the fiscal year following the calendar year in which the study is scheduled to be completed. Matlick et al (1980a) interpret this to mean that the base cost year is the year the full-scale or limited production of the materiel system is projected to begin and are troubled by the lack of citation for the policy.

An important consideration for any cost analyst in making projections is the possibility that the assumptions on which the model is based may change. Sensitivity analysis allows projections to be made of cost and training effectiveness changes if the values of certain assumptions change. Here again Hawley and Thomason offer important suggestions to the analyst recommending that training equipment reliability, availability and maintainability assumptions be allowed to vary for the cost projections. They also recommend considering such changes as a switch from military to civil service instructors or from enlisted personnel to officers in predicting instructor salaries. Performing these analyses would allow the analyst to select training methodologies that are cost-effective for most of the range of likely values for these assumed parameters.

This model expands the TECEP costing considerations by alerting the cost analyst to provide the fullest training description in cost data requests and, through the use of sensitivity analysis, to examine changes in the values of assumptions. Knerr et al (1984a) further note that it can be used to evaluate individual tasks, groups of tasks or the entire program.

Litton Mellonics Training Cost Model:

Matlick et al of Litton Mellonics reviewed the relationships between the development of Army weapon systems and the concomitant training requirements for the ARI Field Unit at Fort Bliss, Texas and published their work in 1980. Their objectives were to provide Army analysts with a performance guide for CTEA at each stage of the Life Cycle. (Matlick et al, 1980b)

They reported that despite Army doctrine, many systems were fielded with most, some, little, or none of the data required for training decisions. Their efforts resulted in the development of an analogous task method which proceeds task-by-task to extrapolate effectiveness and cost of current training of tasks similar to those required for the new system.

They also developed a process to evaluate task criticality to highlight trainability concerns for further research. And, finally, they made significant modifications in the TECEP cost model to (a) make it truly Army-compatible and (b) to include the cost of unit training if proficiency had not been attained at the institutional level.

This model further developed the TECEP variables by modifying the institutional training elements to incorporate both their classroom and field cost elements.

The most significant part of the Litton modifications to the

TECEP equations is the provision of specific sources of information for the cost data. The authors have provided the Army equivalent of the original Navy information sources in a step-by-step Performance Guide.

Like TECEP, the Litton model is intended to aid the CTEA analyst to prepare recommendations regarding relative choices among alternatives. It cannot be used for budgetary purposes. Nevertheless, it is important in collecting data on training costs for the analyst to be familiar with the Five Year Defense Plan and its associated budget programs.

An advantage of the Litton model is the provision of discounted cost figures either by task(s) or by training program. The authors of the performance guide also provide useful instructions on the inclusion of both direct and indirect costs of institutional training.

The costing algorithm presents some problems. Like TECEP, the instructional material development category requires refinement to cost computer-assisted instruction. The model also assumes the instructor to student ratio to be constant from year to year. This ratio is then used to estimate facilities needed and to cost these facilities over the planning period. Self-paced instruction would require a different approach.

As noted earlier, the major contribution of the Litton model is the provision of very specific Army data sources. The performance guide is designed for use by Army personnel who are familiar with, but not necessarily experts in, Army training and task analysis. It also does not require the use of psychologists or mathematicians. By providing the non-expert analyst with a variety of approaches to data situations, it increases the number of personnel available to perform CTEA. Knerr et al (1984a) recommend the Litton model for all CTEA situations in the Life Cycle System Management Model.

TRADOC Systems Analysis TEA Handbook (TRASANA):

This 1980 draft handbook was developed by TRADOC's Systems Analysis Agency at the White Sands Missile Range. Rosen et al (1981) state that the handbook is envisioned as an evolutionary document with the ultimate goal of providing a "how to" guidebook. As outlined in this draft, the methodology describes what should be done to carry out an analysis but is not specific on how to do it.

The handbook advises that an analyst must insure (a) that all costs for support of the training subsystem are included (b) that total costs are captured to allow for valid comparisons and (c) that there be close coordination between the cost analyst and the effectiveness analyst. The handbook contains useful prompts and reminders for the analyst as the CTEA proceeds.

The handbook recognizes that raw cost data received from other agencies will require analysis and transformation into more useful form. The handbook was designed to cover all phases of the system life-cycle, not just the development stage. Its stated intention would provide cost estimates for both institutional and unit training.

In contrast to the models discussed earlier, the handbook recommends that a variable cost, variable effectiveness model is the most appropriate for comparing alternative training systems. The handbook states that neither variable has complete meaning until both are considered together.

No cost model is provided by the handbook other than the very general equation that Total Training Costs equals Institutional Training Costs plus Unit Training Costs. In fact, the authors recommend that cost methodology be "generalized" to allow changes as the analysis progresses.

The handbook provides useful sources of cost data information in addition to those provided in the Litton Mellonics performance guide. It also includes a cost term definition appendix which provides helpful advice on procurement schedule flexibility recommending that different procurement quantity schedules be assessed for both their cost results and their training effectiveness. It also advises that equipment cost data requests include a probable "size of buy" with minimum and maximum parameters so that the cost estimator can establish the appropriate unit cost.

A training cost data appendix provides useful definitions and examples for elements of institutional training, unit training, training system requirements and life-cycle costs. As noted by Matlick et al (1980a), there is no explicit provision for either discounting or the evaluation of residual assets.

The handbook's section on analysis presentation provides some important advice. Noting that decision makers are as interested in the major cost elements, expenditure schedules and other aspects as they are in total cost of a training system, they advise that care be taken to insure that vital ingredients of the analysis are not obscured in some final cost figure. The recommended output would highlight sub-elements of high impact on total costs as well as those whose incremental or decremental change would influence system effectiveness. The total numbers would be appended to this highlighted analysis.

As presented in this 1980 draft, the handbook could be used with a specified cost algorithm to arrive at a more complete cost prediction.

General Model/Methodology for Conducting Cost and Training Effectiveness Analyses:

An earlier effort to develop a TRADOC handbook was produced in 1976 by Vector Research, working as a subcontractor to BDM Services. As noted by Matlick et al (1980a), the guide outlines a process rather than providing a procedure or method whereby inputs lead to precisely defined outputs.

The approach developed by Vector is unique and does not appear to be a derivative of any of the other approaches examined. They examined training for a number of Army systems and identified eight unique systems: large group war games simulators, individualized and/or small group lesson delivery systems, small group practical maneuver and deployment instructional games, program directed hands-on job performance aids, large weapon system practice firing adapters, small group combat engagement simulators, trouble shooting training simulators, and small weapon system practice firing adapters. They then developed weighted measures of training effectiveness for a base system and each alternative.

The cost analysis is extremely simple. The analyst selects a sample system most similar to the alternatives to be evaluated and calculates a per unit cost based on the expected life-cycle number of units used. The costs of the alternatives are multiplied by the fraction resulting from dividing the effectiveness of the base case by the effectiveness of the alternative. This figure is then compared to the cost of the base case. All costing follows training effectiveness determination.

Matlick et al (1980a) state that the alternatives could also be compared with each other in which case the second alternative would replace the base case in the numerator.

As noted by Matlick et al (1980a), this methodology provides no guidance on front end analysis. The decision step linking a training need to one of the eight training methods is missing. They also note that it can only be used for actual training programs where interval or ratio data are available.

It has nothing to offer in terms of training cost prediction in early weapon development. Its costing formula does not reflect either discounting or the consideration of residual assets. It is unclear how student and instructor costs are calculated. Further reviews do not indicate whether the handbook was ever used by TRADOC.

Training Developers Decision Aid for Machine-Ascendant Military Occupational Specialties (TDDA/MAMOS)

Pieper et al of Applied Science Associates developed this methodology in 1978 to assist a training developer in deciding what, where and how tasks within machine-ascendant Military Occupation

Specialties are to be trained. TDDA/MAMOS assumes a usable task list.

The four functional elements of TDDA/MAMOS are: task description, training prescription, training hierarchies and sequence, and training costs. Matlick et al (1980a) note that the training prescriptions are modifications of the TECEP and TEEM approaches. The costing is unique -- and complicated.

This is not a weapon system-based model. It is based on the Military Occupational Specialty, with the tasks for each MOS treated as a single set -- some taught in schools, some on-the-job, and a few given no formal training. After tasks are assigned to resident training or on-the-job training, the model sets up a relative cost formula for feasible alternatives using a cost-rating technique.

According to Matlick et al (1980a), this cost rating technique was justified by the authors because (a) actual dollar costs vary over time while relative differences remain essentially constant (b) ratings can include items such as student time without conversion to dollar amounts, and (c) the various methods of instruction can be ranked on relevant cost dimensions. Rosen et al (1981) also note that the model was attempting to overcome inflation uncertainties and the consequent time-consuming data conversions. It is not clear how the following formulation would save time.

For classroom instruction, TDDA/MAMOS divides the following ten training methods into seven method cost classes: conventional, demonstration, case study, guided discussion, peer tutor, tutor, programmed instruction, traditional practical exercise, programmed practical exercise and computer-assisted instruction. Then the direct and indirect cost variables were categorized into seven classes: square footage, instructor to student ratio, system equipment, furnishing, expendable supplies, training aid development, and training material development. Finally, the method cost classes were ranked on each of the cost variables, resulting in a seven-by-seven matrix of values.

A mean rank is then calculated for each method cost class and a mean rank cost multiplier is also developed. Then the number of hours of each method within the training cost option is multiplied by its cost factor to get the Method Cost Indicator. This MCI for all methods within the training option is then summed yielding a Resident Option Cost Indicator.

With the exception of computer-assisted instruction, the cost method classes and cost variables were also calculated for On-The-Job training to obtain an OJT Option Cost Indicator. The two were then summed to produce a Training Option Cost Indicator.
This TOCI is then used to establish a ratio of one training option to another, giving the training manager an indication of relative cost.

Matlick et al note in their 1980 review that TDDA/MAMOS had not yet been fully developed and would require an extensive validation effort to demonstrate its usefulness and the precision of its outputs. In their 1981 review, Rosen et al indicate that TDDA/MAMOS is rarely used.

As noted earlier, this model would not be useful in the development stage of a weapon system and has no relation to the life-cycle costing of a system. Even for its stated purpose of devising different training strategies for Machine-Ascendant Military Occupational Specialities, its formula for developing a relative cost indicator is intimidating.

Multiple Launch Rocket System Repairer Cost and Training Effectiveness Analysis (TRASANA TEA MLRSR):

This CTEA was conducted by the Army TRADOC Systems Analysis Activity (TRASANA) in partnership with the Army Missile and Munitions Center and School (MMCS) in 1984 to evaluate the relative cost and training effectiveness of four training alternatives generated by the MMCS to train 135 students per year. MMCS is the proponent for individual training required to support the Multiple Launch Rocket System.

The major hardware subsystem component of the MLRS is a tracked, self-propelled launcher loader(SPLL). The original eleven week Program of Instruction (POI) anticipated training 135 students per year with ten SPLLS for hands-on experience. Only three SPLLS were permanently assigned to the MMCS with a fourth on a more or less permanent loan. This CTEA was conducted because of the equipment gap and anticipated obtaining training device(s) to fill that gap. It is included here as an example of the effort required when the in-place training devices are other than those projected in the original Program of Instruction and as an illustration of incorporating TECEP and TRASANA TEA handbook instructions.

MMCS generated several combinations of SPLLs and anticipated training devices and included the original plan as the baseline. Subject matter experts were used to rank the effectiveness of the baseline and the alternatives. The five methods were compared on their research and development, investment, operating and maintenance, and instructor costs. The costs reflect the equipment use and instructor hours for blocks of instruction which require equipment.

The cost estimates combined both actual experience and comparisons. For example, the MMCS used nine months of experience with four SPLLs to estimate operating and maintenance costs. The operating and maintenance costs for the trainer were estimated by the project manager's office who decided that student and instructor stations were equivalent to the cost of the fire control panel trainer used at Fort Sill.

TRASANA computed instructor costs for baseline and alternatives by estimating the maximum and minimum number of instructor hours needed for each block of instruction. The variability of instructor costs, operating and maintenance costs and the variability of electrical power costs for the trainer led to the presentation of the data in a high total cost and low total cost format for the baseline and each alternative. This follows the guidelines in the TRASANA TEA handbook which call for presenting the sub-elements which have the highest impact on costs. Student costs, and costs for buildings and instructors in a classroom were considered equal for the baseline and alternatives and were factored out, reflecting the TECEP approach.

Another table presented the ranked cost comparisons alongside the ranked training effectiveness comparisons. Again, this is the tradeoff display recommended in the TRASANA TEA handbook.

This CTEA was conducted to assess training effectiveness and costs in an institutional setting after a training equipment gap developed. The comparison-based costing estimate for the trainer which had yet to be developed would provide some guidance for the development stage of a weapon system. It would not provide budgeting information.

Comparison-Based Prediction of Cost and Effectiveness of Training Devices: A Guidebook,(CBP)

This guidebook was developed for the Army Research Institute by Klein Associates in 1985 in an effort to assist the Army in the evaluation of training devices early in the weapon acquisition cycle. According to its author, it represents a refinement and improvement of the comparability analysis approach which has been used by the Air Force since the 1970's to predict equipment reliability for purchasing, manpower projections and downtime forecasts.

The methodology is not a derivative of any of the previously discussed models. The author argues that a technique is needed that is between unstructured expert judgments and complex data-driven models. The author criticizes unstructured expert judgments as subjective, difficult to evaluate or to justify to others. On the other hand, he notes that complex models require data that are not available to feed decisions early in the life-cycle.

The CBP solution to these problems involves structuring expert opinion, using data available on similar cases, and providing an audit trail of these judgments so that they can be evaluated, compared with other predictions, and adjusted as the design process advances.

Describing CBP as a method of reasoning by analogy, Klein uses the illustration of a potential homeseller turning to an appraiser for assistance, having the appraiser identify both the important factors that influence price and similar recently-sold homes. Klein likens the appraiser's documented estimate to a subject matter expert who provides the training developer with a recommendation based on important causal factors with sufficient documentation to provide an audit trail for evaluating the decision. In a section entitled "Setting up the Problem", Klein's analyst has decided on a proposed training device description, measures of training effectiveness, and important causal factors. The analyst then examines existing devices to see if there is a match. It is not clear from the guidebook why a particular training device is being considered for the new weapon system, how the training effectiveness measures were developed, or how the causal factors were selected.

After finding a similar training device or devices, the analyst then arranges to interview the subject matter expert(s) on the device(s). Klein places great emphasis at this point on drafting a guide for the interview so that identical descriptions will be given to each subject matter expert on the proposed device. The subject matter expert is asked to compare the system with which he is familiar with the analyst's proposed device and features and to make comparative effectiveness or comparative cost predictions. A written record is maintained of this interview.

Some problems may occur during this interview. The analyst has already decided on the comparison case which is how the subject matter expert (SME) is selected. That step also included establishing measures of training effectiveness and causal factor decisions. Klein notes that the SME may suggest a better comparison device, other causal factors, or better Measures of Training Effectiveness (MOTE) based on experience. This would require a new comparable device SME interview, and a new round of causal factors and MOTEs. Klein forecasts this iterative process with a circular flowchart, but does not indicate at what point the reconsideration and reinterviewing would cease.

Klein recommends several alternative strategies for structuring the comparison-based application depending on time constraints, abundance of comparison cases, availability of data, and identification of SMEs.

These involve: (a) a "global" strategy based on interviewing one SME, asking for a judgment on the proposed device based on the SME's experience with the comparable device, (b) a "high driver" strategy involves asking the SME to detail how the target case and the comparison case differ, and how much each of the high drivers affects the difference, (c) the "multiple comparison case" strategy which increases confidence if the same prediction is reached independently through the use of different comparison cases. He suggests this strategy could also involve the judgments of multiple SMEs, that if these multiple judgments converge, the confidence level is raised. He does not discuss what to do if there is multiple judgment divergence. (d) He then suggests a "cumulative" strategy, adding SMEs until there is enough agreement to "feel confident". If there are disagreements, Klein feels the audit trail will reveal the basis for the difference.(e)Klein finally states that if there is one SME whose judgment is valued most highly, then that is the SME to be used.

It is not clear how these subjective approaches differ from those Klein has criticized and is attempting to replace. Klein's strongest recommendation for the CBP method is the keeping of a written record, the so-called "audit trail" for the decision. He states that if the prediction is found to be inaccurate once operational data are obtained for the target case, the audit trail provides "an opportunity to identify which considerations (causal factors) were responsible for the misjudgment." (1985,p.A-4) It is not clear what steps follow identifying these misjudgments.

The audit trail suggested here and by others can be a valuable tool, but it would not address, in this instance, selecting the wrong target training device in the first place.

There is a suggestion throughout the Klein methodology that a new weapon system will be a <u>replacement</u> for a current system, and that training devices for the new system will involve only incremental changes from existing devices. The approach does not involve assessing present methods and devices for inadequate training. In reviewing a 1982 version of this methodology, Knerr et al (1984a) note that it has promise if the information of interest is the relative merits of potential devices.

There is no clear link between training effectiveness and cost in this method. The SME is asked to make a relative judgment about a pair-wise combination for either effectiveness or cost changes. The approach could be used to refine those steps in more complete methodologies where estimates must be used.

Cost-Effectiveness Specification for Computer-Based Training Systems:

This methodology was developed by Seidel and Wagner of the Human Resources Research Organization for the Defense Advanced Research Projects Agency and published in 1977. It was designed to facilitate the purchase, monitoring and evaluation of computer-based training systems and is the first methodology reviewed here directed solely to training which is administered, aided, or managed by computer. It provides a standardized structure through which training system costs can be derived and used in the preparation of cost and effectiveness estimates.

The cost methodology is focused on identifying and quantifying the total inputs (men, money, material) required by a computer-based training system throughout its life-cycle. Identified inputs are costed in terms of development, procurement and operating and maintenance costs to attain and sustain a training capability over a fixed period of time.

A Training Cost Breakdown Structure is used to specify all the major cost categories of resources that are required for Computer Assisted Instruction (CAI). This is a significant addition to the work reviewed to date and can be used to address the CAI weaknesses noted in the instructional material development cost categories of both TECEP and its Litton modification.

This is not a weapon-specific model but a technology-specific model. The model assumes an institutional training setting.

For purposes of this methodology, Seidel and Wagner assume the life-cycle phases to be sequential and of a pre-set arbitrary length. They use 6 years for development, one year for procurement, and up to 8 years for operations and maintenance. The model also assumes instantaneous rather than phased-in fielding of the system. For training effectiveness measures they suggest objectives-based achievement or time measures for within-course and end-of-course criteria. They also discuss measures such as attrition rates, instructor ratings and attitude scales.

While effectiveness criteria do reflect training requirements, this specification -- like TECEP -- does not establish effectiveness priorities. They do provide guidance to the trainer/decision-maker to weight effectiveness measures according to the training requirements that drive the analysis.

Development phase activities include applied research, engineering design, analysis, development, test, evaluation and management related to a specific computer-based training system. Included in the procurement phase are fabrication, communication, reproduction, packaging and shipping and other activities necessary to transform or copy the tested prototype system into a fully operational system. Operations and maintenance activity costs would include replacement training for site personnel.

Seidel and Wagner separate the work effort into three parts by life-cycle, suggesting that one individual be responsible for completing the specification at each stage and also suggesting that for the entire development stage and part of the procurement stage, the contractor would be the source and/or collector of the needed information. These two suggestions may present problems.

While they note that the requirement to have the same individual perform the data-gathering and analysis at each phase might involve a resource needed elsewhere, they insist that it is the only approach that permits data collection consistent with the guidance and formats provided in this specification. The reality of military rotation presents an additional drawback to this requirement.

Also, contractor-supplied information in the early development stage appeared such a problem to Matlick et al in their 1980 review that they recommended that explicit contractual requirements be developed to assure that all developmental data needed for CTEA analysts became available in timely fashion.

For the establishment of a cost-effectiveness ratio, Seidel and Wagner begin with the assignment of values or priorities to various dimensions of training effectiveness. These authors feel that a reasonable cost-effectiveness analysis would compare the best estimates of <u>future</u> operations and maintenance costs and <u>not</u> include costs that were expended in the past. They suggest that the ideal case would involve comparing the cost-effectiveness of two alternative training systems when they are in their operations and maintenance phase, and strongly warn against making cost-effectiveness judgments in the development stage.

They do however provide several examples of cost-efficiency outputs that could be obtained during the development stage. If training requirements have been established and graduation signifies criteria attainment, they suggest two ratios as indices of efficiency: (a) projected graduation cost per graduate either for all courses supported by the system or on a per-course basis and/or (b) projected hourly cost of instruction per student hours, again either for all courses supported by the system or on a per-course basis.

Their procedures could also be adapted to judge the efficiency of a computer-based system in aiding in the development and revision of training materials independent of any training effectiveness judgment. An additional benefit would be the capability of judging a system's efficiency in scheduling training resources and equipment and keeping records. Seidel and Wagner provide an important caution against confusing another efficiency judgment -- the number of students completing courses -- with training quality.

Their approach to the alternative comparison method involves either (a) holding effectiveness constant and allowing cost to vary or (b) holding cost constant and allowing effectiveness to vary. They caution against the approach recommended in the TRADOC TEA handbook of allowing both cost and effectiveness to vary. They state that this may lead to a fallacious attempt to minimize cost and maximize gain at the same time. They feel strongly that infinite effectiveness at zero cost is an untenable goal which should not guide the cost-effectiveness analysis.

This methodology offers additional guidance in costing computer-based instruction, underlining the importance of considering all appropriate costs and benefits during the entire operational life of a system. In this way, "cost avoidance" factors such as fewer instructional personnel or facilities or less training time -- which may accrue over several years -- will be permitted to surface and balance the large initial capital investment costs of implementing a computer-based training system.

The model makes appropriate use of economic concepts and includes indirect costs and inherited assets. Its application assumes formal, school-based training. The model provides extremely useful guidance for including all the relevant costs for computer assisted training. It is unclear if the model has been validated.

Computer-Based Job Skills Education Program (JSEP)

Another development in computer-based CTEA was reported by Richard Kraft of the Center for Education Technology at Florida State University and Beatrice Farr of ARI. They discussed several key cost and training effectiveness variables that would be used to analyze the Job Skills Education Program for ARI.

The Job Skills Education Program (JSEP) is described as "designed to provide soldiers with job-related basic skills instruction that is prerequisite to learning their skill level 1 and 2 job tasks during their first duty assignment. Based on extensive job analysis of the 94 largest MOS tasks contained in the Soldier's Manual of Common Tasks, JSEP provides functional basic skills instruction on MOS specific requirements." (1983,p.1).

It appear from reading this "first draft" that a decision has been made to teach these tasks with computer-based instruction, that JSEP itself is still in the conceptual stage, and that the decision involved is the choice of the right configuration of personnel, terminals, and sites. The methodology will not be weapon system-related.

The authors were planning to develop a model which will address JSEP's "unique" requirements, including "the self-paced nature of JSEP (which) rendered assumptions underlying some existing CTEA models inappropriate" and the "open entry, open access characteristics" of the program which require open system methods as opposed to closed system. (p.vii) The authors hope to have a predictive CTEA model developed by the time the JSEP system has been fully defined.

The draft describes the steps in this development as defining operational functional constraints, defining appropriate training configuration possibilities, and quantifying the advantages and disadvantages of each design alternative for individual site-specific requirements.

The proposal anticipates combining research and development costs, investment costs, operating and life-cycle costs with the number of students per site, the student flow rate, a system usage ratio, the rate of completion of assigned lessons, and the average number of hours of instruction per student to completion to produce costs per terminal hour, cost per instructional hour, class hours per training center, hourly cost per graduate and direct cost per graduate.

The next stage of JSEP development will determine whether the cost analysis will be only "real" cost oriented, or whether it might include consideration of "sunk costs and other intangible cost elements." (p.3)

The proposed development steps for constructing the costing model are fairly routine but they do include a step to describe non-quantifiable elements of training cost and a proposal for "integrating CTEA with a decision-oriented multi-criteria utility analysis." (p.4)

The draft describes an ambitious effort which, depending on data availability, could present "cost per terminal hour", for instance, as a function of the cost of hardware and software, courseware, design and development, hours of usage per year, number of terminals installed relative to the total number which can be managed by the central computer, operations, supervision, and maintenance. (p.4)

Even more ambitious is a proposal to "investigate the range of qualitative effects of alternative configurations to see whether any benefits not readily expressible in dollars could perhaps be analyzed using rating scales and evaluated in terms of 'equivalent dollars', for example, the effect on projected re-enlistment rates by a configuration." (p.4)

As indicated by the authors, this is a first draft which will undergo several revisions. Attempts to obtain an updated version were unsuccessful. There are additional costing objectives briefly outlined in this draft which need further clarification. The proposed CTEA will include sensitivity and contingency analysis and costs will be presented in present value form.

In developing the cost model, the authors list several models which will contribute to the effort. These include TECEP and the Cost-Effectiveness Specifications developed by Seidel and Wagner reviewed earlier. Also listed is an Educational Technology Assessment Model (ETAM), developed by IBM for the Navy and described as a follow-up of TECEP. ETAM's main objective is described as "quantifying the impact of educational innovation upon existing courses." (p.21)

Another cost model listed in the proposal is one developed by Saisawan Vadhanapanich for a doctoral dissertation at Florida State University in 1975. Kraft describes this cost effectiveness model as "an integration of the separate cost and effectiveness models. Ths purpose of the integrated model is to combine the cost per student contact hour and probability of system effectiveness into one index for each course of action examined." (p.21).

The Vadhanapanich model described in the dissertation is designed for a non-service environment and does not account for the costs involved for a military student, such as pay, housing, benefits,etc. It appears to be designed for a civilian education decision maker who must decide in what year to purchase computer-oriented instructional media. The proposal does use discounting and considers residual assets. It has not been validated.

As noted earlier, the JSEP-CTEA proposal is in first draft form and revisions were anticipated. ARI's Technical Director anticipated that when all phases are completed "Army decision makers should have considerably better cost and training effectiveness data to help them select the future Army CBI system". (foreword)

In their review of cost models in 1980, Matlick et al noted useful elements in several powerful models developed for the Air Force by various contractors. These efforts were not incorporated into their developed model because they would have required substantial revisions in Army practice. A review of several of these contractor developments and an evolution into an Army-compatible methodology follows.

B-1 Systems Approach to Training (B-1 SAT):

Calspan Corporation developed a training program for the air crew of the future B-1 strategic bomber using a systems approach to training in 1975. Matlick et al noted that Instructional System Delivery prescriptions are seldom followed as rigorously as they were in this case. This is the most ambitious attempt reviewed to assure that the entire training system is considered within an orderly and complete process.

The training system provides for transition, recurring, and upgrade training for the four aircrew positions. The instructional system development was enhanced by the concurrent development of two computer aids . These involve a sorting model which allows efficient storage, retrieval, collating, and updating of mission/function/ task analysis and supporting data. Behavioral objectives are arranged hierarchically and examined in light of probable entering student qualifications. Training device requirements were identified using guidance from TECEP modified to reflect the special requirements of the B-1 SAT.

A major goal of this approach was to increase training cost-effectiveness by eliminating unnecessary training and overly elaborate training devices while training the aircrew to the performance criteria.

The second computer aid is called the Training Resources Analytic Model (TRAM) and is used to structure and schedule courses, tracks and instructional blocks. The program examines the proposed training system's resources, schedules and costs. TRAM is exercised for the tradeoff analyses between resources and instructional contexts. Commonalities among objectives might suggest their grouping within a certain instructional context but this may be contradicted by the cost of using training devices and facilities in such a way.

A computerized ability to perform this clustering and the subsequent costing would be a significant improvement in the models thus reviewed. This automated approach also developed different tracks of training depending on expected skill and knowledge levels of entering students. Another output from TRAM is time-phased life-cycle costs and resource requirements for the training system.

An additional significant advantage of the systems approach used for the B-1 SAT is the provision for trade-off and sensitivity analysis of such features as ratio of hours spent using various training media, centralization of training facilities, and training media time phasing.

The final outputs from this program include: (a) a description of recommended and alternative training systems (b) a syllabus for each course and (c) description of required media and facilities, costs and schedules.

The initial source of information for the effort is the original task analysis data. The quality of this data base establishes the potential quality of the system recommendations. It appears from this application that the Air Force has a data base which is sufficiently developed to use factors for such items as research, development, testing, evaluation and other preproduction costs including the cost of the first unit of training. Cost estimates for annual operation and maintenance, instructor personnel, trainee temporary duty, the direct costs of the aircraft, equipment operation, maintenance and upgrade, instructional material and facilities are all calculated using factors and average lead times. It would be a significant advantage if Army cost and training analyses efforts could lead to such a data base.

An added benefit of the B-1 SAT approach was the assignment of a data quality designator to each cost element. Cost data sources included manufacturers, government facilities and simulation users. A rating system indicated predicted accuracy of cost data.

The cost output included life-cycle costs and used the constant dollar base year approach. The methodology is training-prescriptive and cost-predictive and the model is system-specific. Jorgensen (1979) felt the real value of the work had been overlooked, possibly because of the cancellation of the B-1 program. (The B-1 is scheduled to be replaced by the Stealth plane. Controversy about this replacement has continued into the time of this writing).

Method of Designing Instructional Alternatives (MODIA)

The Rand Corporation developed a methodology for the Air Force for the design and cost analysis of an instructional system. The results were reported in five volumes in 1977 including an overview of MODIA, options for course design, a user interface, a resource utilization model and a cost model called MODCOM.

MODIA is computerized and is designed specifically for formal training in the five Air Training Command (ATC) technical schools. The ATCs account for the bulk of Air Force technical training. The authors note that over one-third of the 300,000 different course hours in the technical training curriculum are substantially revised or newly prepared annually and provide many opportunities for improvements in the management of training resources.

MODIA is described as "a systematic process for planning the mix of students, instructors, materials, equipment, facilities and the procedures by which all of these elements work together." (Vol.4, Summary). It can be used to design new courses or redesign existing courses.

The "options for course design stage" includes guidelines for design choices based on objectives, student population, teaching policy and resource constraints. The second stage involves an interactive question and answer dialogue between user and computer which expands objectives into learning events and develops a full course description including teaching strategy for learning events. Charles Jorgensen of ARI (1979) found this step valuable because it allowed the users to see the impact of trade-off decisions they have made at each stage of the process.

The results from this second stage are fed into the Resource Utilization Model (RUM) which simulates the operation of the course over time and produces detailed reports on resource utilization and demand as well as student flow patterns. The RUM can be manipulated to reflect the inexact nature of such events as arrivals, student ability levels and other parameters.

The RUM simulations are then fed into MODCOM, the cost model, which provides total course costs including personnel and resource life-cycle costs. Some of the requisite cost and manning factors are stored in the program while others are supplied by the user.

MODCOM analyzes manpower and other training expenses for training design impacts. The manpower categories include students, instructors, administrative personnel, curriculum personnel and hardware maintenance personnel. Other cost categories are courseware procurement, hardware procurement, facility construction, pay and allowances, instructor training and miscellaneous operating expenses. The outputs of MODCOM are graduates by student type; student and staff man-years; courseware, hardware and facility characteristics; total course costs by functional element; and total course costs by program and appropriations.

MODIA is not weapon-specific and the authors describe it as neutral in regard to the effectiveness of training design. As Matlick et al (1980a) note, the original input to MODIA is the product of subject matter experts in planning and developing courses but this stage is not specified in the model. They further note that MODIA could be used to compare well-developed training program alternatives but that its required level of detail makes it unsuitable for the early stage of the life-cycle of a weapon system.

The cost model uses a five year time horizon, which is a rough approximation of the time a technical training center course continues before being completely revised. The model considers incremental costs, excludes sunk costs, and produces discounted costs and benefits. It also considers inherited resources and residual values. Model results cannot be used for short-range budgeting problems.

MODIA depends on the existence of a consolidated data base and, as noted by Matlick et al (1980a), it would require substantial revision to be suitable for Army use. Nevertheless, there are several elements in its cost model algorithm which should be considered in the model to be developed. These include (a) the cost per instructor of initial factory training. This computes the cost of providing an instructor in the initial cadre with the specialized equipment or system training he needs for developing and conducting a course. The model assumes this initial specialized training is accomplished at a private contractor's facility with subsequent training of instructors provided informally by the existing instructor nucleus (b) The model accounts for the different personnel costs related to students and instructors on temporary duty (TDY) or permanent change of station (PCS). The latter would consider the costs of transportation of personnel and dependents, and shipment and/or storage of household goods.

If it is not possible to represent computer use in dollar terms, MODIA's authors suggest selecting some other measure of resource utilization such as Central Processing Unit seconds or number of core bytes used and keeping track of that utilization outside the cost model.

As noted earlier, MODIA would not be helpful in the early development stage of a weapon system and would require substantial revision for Army use. Jorgensen (1979) feels that MODIA's value lies more in the area of program management than in actual course development.

## Digital Avionics Information System: Training Requirements Analysis Model (DAIS/TRAMOD)

The Training Requirements Analysis Model is a computerized analytical model developed by Czuchry et al of Dynamics Research

Corporation for the Air Force Human Resources Laboratory and published in 1978.

Like MODIA, it is a computerized means for training design but it makes design decisions rather than simply revealing the impact of decisions already made. The model is used to decide which among a group of tasks should be trained, and how -- given a series of constraints -- to best accomplish a well defined set of training objectives.

TRAMOD is designed to operate in conjunction with a reliability and maintainability model and a system cost model to form a Life Cycle Cost Impact Modeling (LCCIM) system for use in the early stages of system design. The LCCIM system was developed as part of and was to be applied to the Digital Avionics Information System advanced development program. Each model within the LCCIM addresses a component function of life-cycle costing. TRAMOD addresses the training requirements element of system LCC.

TRAMOD operates from a task data base whose preparation is described by Matlick et al as a manual task of "considerable difficulty". (1980a,III-18) The task input includes the assignment of values to a number of parameters: criticality, learning difficulty, frequency, psychomotor level, cognitive level, and estimated time required to accomplish training. The authors suggest that "...the values assigned to the task characteristic parameters should be based on the judgments of engineers and technicians familiar with the equipment upon which the tasks will be performed." (1977,p.12) Matlick et al (1980a) consider this a major change in the way hardware manufacturers currently perform task analysis and feel this would constrain successful use of the method.

Selecting from the input lists the tasks to be trained, the user interacts with the program specifying constraints on the selection of tasks and develops blocks of tasks to be trained. Once the training blocks have been determined, TRAMOD prints a series of questions to which the user must respond to indicate how the training times and costs for the task blocks are to be derived.

Three cost options are available: (a) direct input of training time and costs for each task block in the input data set (b) calculation of training times and costs with user-selected regression coefficients, with training time and costs being linear combinations of the task characteristics (c) derivation of training time and costs with fixed default regression coefficients stored in TRAMOD.

The program uses a combination of optimizing and mapping techniques and results in specific task blocks to be trained with recommendations on training mode (school or on-the-job), method of instruction and media. It also includes a time estimate and a cost estimate. These data are fed into a training program generator which schedules resources and tasks for training.

Designed for use early in the systems acquisition process to facilitate the identification and timely consideration of potential training problems, the model's primary objective is to enhance Air Force ability to avoid potential training problem situations through action within the design process itself.

TRAMOD uses comparable operational equipment data values for these early development estimates. Course length and cost data information for the technical training schools was available but on-the-job training times and costs had to be estimated.

The final output from TRAMOD includes a schedule showing the order in which tasks are to be trained, whether a task is to be trained in OJT or school, the days required to train each task, the cost of training each task, and the method and medium for each task. The model provides for rerunning program, altering decisions and comparing results.

TRAMOD considers costs but not effectiveness. The method is cost prescriptive rather than predictive. It is not clear that economic concepts such as discounting and residual assets are included in the costing estimates.

Matlick et al (1980a) feel it would be valuable for comparing training alternatives resulting from various constraints such as training time limits or equipment shortages. But, like MODIA, the model would require substantial revision for Army use.

Coordination of Human Resource Technologies (CHRT):

In yet another Dynamics Research Corporation effort, Goclowski et al developed Coordinated Human Resource Technologies for the Air Force Human Resource Laboratory in 1978 as human resource assessment tools.

This ambitious effort combines five technologies in the Weapon Systems Acquisition Process (a) maintenance manpower modeling (b) instructional systems development (c)job guide development (d) system ownership costs and (e) human resources in design tradeoffs.

The objectives were to integrate and apply the technologies to form a Coordinated Human Resource Technology (CHRT). The second objective was to design a consolidated data base to support CHRT application by establishing a common source of information for human resource technology early in the acquisition process.

A Consolidated Data Base (CDB) is established for each weapon system in the acquisition process and it grows as the system develops. The five technologies draw on the CDB for input and many of their outputs go back into CDB. The aim is to have one data base containing information on reliability, maintainability, maintenance manpower, operation manpower, training, job guides, and system ownership cost. It is designed to support human resource planning during the acquisition process and then to support operations and logistics planning after system deployment.

The Instructional System Development (ISD) in CHRT results in training concepts during the concept phase of a weapon system, a training plan during the validation phase, and a fully-developed training program during the full-scale development phase. Knerr et al (1984a) note that the ISD phase does not deal with features within training devices and does not predict device effectiveness or transfer.

The Human Resources in Design Tradeoffs phase identifies points in system development where the selection of alternatives has a large impact on human resources.

The costing portion -- System Ownership Costs -- was not fully developed at the time CHRT was published, but the authors were attempting to develop a model to identify the real ownership cost drivers. They suggested it might be necessary to tailor SOC for a particular system during the conceptual phase, and the model effort appears to be aimed at operating and support costs rather than acquisition costs.

At the time of publication, the System Ownership Cost components were to include (a) support investment costs which included equipment, job guides and spares;(b) operating costs which included cost of aircrew and fuel; and (c) support cost, which included cost of depot repairs, inventory management, technical record data, equipment maintenance and personnel training. These costs were to be described in constant dollars.

The authors were planning to test and refine the methodology using data from the advanced medium Short TakeOff and Landing (STOL)transport. At the time of their 1980 review, Matlick et al had not been able to identify a report on this effort. Like MODIA and TRAMOD, this Air Force development would require a major conversion effort for Army use.

Military MANpower and HARDware Procurement (HARDMAN)

Dynamics Research Corporation continued its efforts to develop human resource assessment tools. In 1980, they published their HARDMAN methodology for the Navy. This is another effort to determine manpower, personnel and training requirements during the early phases of the weapon system acquisition process and was to involve six steps:

(1) Establish a Consolidated Data Base by developing a reference and a conceptual system and evaluating the design differences between them. This step also involves identifying, collecting and formatting the data required for the data base.

(2) Determine Manpower Requirements for the conceptual system using the reference system as a point of departure. Changes in manpower requirements are functions of design differences identified in Step 1. Knerr et al (1984a) note that this step assists the user in providing the input data for a manpower model rather than being a manpower model in itself.

(3) Determine Training Resource Requirements: A conceptual training program is constructed using the predecessor and reference training program to reflect system design differences. The impact of task and course changes are aggregated to determine estimates of training, costs and resources. Knerr et al (1984a) note that the task action verbs are analyzed using TECEP task categories. They also note that this step estimates formal school training costs but not on-the-job training; that while the methodology identified the need for new construction, it does not estimate those costs; and that it makes no estimates for civilian and officer training.

(4) Determine Personnel Requirements: This step determines the total personnel demand of the reference and conceptual system which consists of personnel required "on hand" to operate and maintain the system and the pipeline personnel who must be "grown" in the system to consistently meet the manpower requirements detailed in Step 2.

(5) Conduct Impact Analysis: Determine the supply of those manpower and training resources required by the conceptual system and measure that supply projected against the demand determined in Steps 2 through 4. This step identifies new requirements for skills, training and training resources, design and other sources of high human resource demand, requirements for scarce assets, and high cost components in the conceptual system. When originally developed, this step was presented in outline form since it had not been validated.

(6) Perform Tradeoff Analysis: This step prioritizes the critical requirements according to their impact on resources available. A range of potential solutions to each requirement was to be iterated to develop the most effective response to each critical resource requirement. Again, at the time of original development, this was presented in outline form without validation.

Reviewing several applications of the methodology in 1984, Knerr et al note that personnel who apply HARDMAN typically have had military experience, have engineering backgrounds and have performed task analysis in the past. They consider the process which identifies the reference system somewhat of an art form.

In 1981, Dynamics Research Corporation reported on the results of a request by the Army Research Institute to test the feasibility of using the HARDMAN methodology (developed for the Navy) to determine the Manpower, Personnel and Training (MPT) requirements of an emerging Army weapon system. They reported at that time that the methodology had already benefitted the Navy by influencing the choice of a ship's propulsion system based on adverse MPT impacts for the original design.

ARI established the following objectives: (a) determine the ability of Army data to support the methodology (b) determine the utility of existing HARDMAN tools for Army application (c) adapt when necessary both the data and analytical tools to the policy and procedural requirements of the Army's acquisition process (d) demonstrate the feasibility of the methodology for Army use by applying its first four steps to a major Army weapon system.

As reported by Dynamics Research Corporation (DRC), the results appear to support a general conclusion that HARDMAN is applicable to Army systems. They note that while data of sufficient quantity and quality were not present for all systems, the data that were present were very good. They also reported on an apparent fragmentation of responsibility in the early phases of the Weapon Systems Acquisition Process which led to the lack of coordination and delays in receipt of essential data. While noting that the Army recognized the problems, DRC pointed out that this inhibited a more extensive front-end analysis for this application.

Like other developers, DRC recommended the establishment of new Army data bases and the expansion, integration and reorganization of existing data bases to support the front-end analysis.

The cost of personnel which must be supplied for the predecessor, reference and conceptual systems were derived by multiplying the manpower requirements by the Composite Standard

Rates for Military Personnel Service found in the TRADOC Resource Factor Handbook. The bottom line value for each system reports on annual cost to support the manpower requirements.

Training resources and costs were estimated for a "steady state year" defined as the first year in which an Army training system is producing replacement training only, that is, all systems have been deployed and training is focused on filling vacant billets. Training associated with the Operational Test and Evaluation Tests of the proposed system and training associated with initial fielding are not estimated during the Training Resource Requirements Analysis (TRRA) step.

TRRA attempts to estimate costs and resources associated with "first order" baseline design impacts only. That is, TRRA will estimate the resources and costs associated with training the personnel who will operate and maintain the system or subsystem. A second order impact -- such as requirements for training of instructors -- or a third order impact -- such as the requirements for the training of training instructors -- are not included. This is based on the assumption that the first order impacts produce the bulk of the operational and support costs associated with the system.

The costs produced by the HARDMAN method were individual student cost per course, average individual training cost, replacement personnel training cost, cumulative personnel training costs, and instructor costs.

Since this initial feasibility test for ARI, the HARDMAN methodology has been transformed into Army-compatible handbooks and applied to several Army systems. The Army adoption of the HARDMAN technique has been criticized by Hawley (personal interview, 1985) who faults HARDMAN's assumptions that current operations are effective and efficient and that future decisions will involve more or less of the same.

In addition to this lack of effectiveness testing, the costing in TRRA ignores what may be significant portions of training costs in the early development and fielding phases of a new system, and outputs personnel "replacement" costs only for a fully-deployed weapon system. It would require major modification to provide the information needed for an early development stage CTEA.

A parallel development to HARDMAN, solely Army-related, has been underway since 1981. A review of the evolution of this methodology for decision-making follows.

<u>Training Development Decision Support System (TDDSS):</u>

TRASANA supported the development of an automated CTEA methodology and decision support system by Applied Science Associates. An evolving technology, the Training Development Decision Support System has been described at various training conferences since 1981. It has been applied to several training situations. Its task selection procedures are based upon Instructional System Development guidelines while its total approach attempt brings it close to the output discussed in the B-1 SAT program.

As described in 1981, TDDSS could be used with developing as well as already fielded equipment systems. An important contribution of TDDSS is its thorough human factors oriented front-end analysis of the job and its tasks. This produces decisions involving training requirements, training system design, device specifications, training management, course design, system design, performance assessment and training support plans.

While the primary purpose of TDDSS is to generate data for cost and training effectiveness judgments for pre-defined performance objectives, an important secondary output of the methodology is the provision of a significant portion of the structure and content for actual course design -- the proposed Program of Instruction.

TDDSS provides a rational objective basis for selecting tasks for training and generates information for designing the entire training system for the Military Occupational Specialty. This would include maintenance and wartime preparatory training requirements in addition to the resident, unit or refresher training described in previous models.

In making cost and training judgments, it is important to identify constraints which will impact on design, delivery and management of a course. An important advantage of TDDSS is that most of these constraints are identified during the generation of a course structure. Constraints can include time and resource availability, instructor number and qualifications, instructional method, philosophy and available media and training devices. As noted by one of its authors, this approach has the advantage of allowing for the consideration of such factors as the reliability and maintainability of a training device and for the calculation of the impact of a considerable amount of downtime for a device. He noted, for example, that considering this variable might lead to a decision to select several part-task trainers rather than a single full-task device whose downtime would create serious bottlenecks in the training program. (personal interview,1985)

After a general course structure has been developed, the next step in TDDSS is to specify Training Program Alternatives (TPA) to meet training objectives. While the authors of TDDSS describe the manipulation of such variables as training time (peacetime, shortened peacetime, mobilization time), types of simulators, logistical support, student characteristics and numbers to develop these TPAs, they warn that the actual selection of training alternatives is not a question of a free choice of variables or levels of variables but is importantly influenced by school philosophies, doctrine and local standard operating procedures.

The final selection in TDDSS establishes "benefit-affordability", first dividing the alternatives into acceptable and unacceptable sets based on effectiveness, then choosing affordable sets from the acceptable sets. Hawley does not feel a variable cost, variable effectiveness approach is viable.

Elements included in the TDDSS resource costing are similar to several previous models and are developed for each alternative using the incremental approach, i.e., eliminating all common costing elements.

The choice method in TDDSS differs from previous methods. The authors suggest (a) identifying two extreme levels of a few variables that would have the greatest impact on cost and effectiveness estimates and then proposing those extreme combinations as the alternatives or (b) selecting the alternative most acceptable to school personnel under their constrained conditions and one or more ideal alternatives that essentially ignore the constraints. They suggest that the school could then work toward the ideal alternative.

By 1983, many of the decision processes of TDDSS had been computerized. A spreadsheet was described which would allow for rapid cost estimation and re-estimation as part of a cost sensitivity analysis. Training site selection (resident or on-the-job) was also automated by this time.

The TDDSS approach appears the most promising of the models reviewed to date. Knerr et al (1984a) note that it fills a need for integration of device prediction and prescription models with models that address whole training programs. While not totally successful, reports at various stages of the model development indicated that an attempt was ongoing to build a consolidated data base for a weapon system which would be a considerable improvement for Army systems.

TDDSS responds to the probability that there will be analyst turnover by leaving various decision audit trails. It does require highly-trained learning specialists and considerable time for the front-end analysis.

The production of a program of instruction and course which results from the front-end analysis in both this and the B1-SAT approach does raise one technical question. It produces some instructional development cost within the CTEA itself. It is not clear if this could or should be separated and included in the system's cost and how it would then be evaluated.

## IV. LESSONS FROM THE LITERATURE

Much of the progress in CTEA modeling in the past decade appears to be concentrated on the training effectiveness side of the issue. The measurement of cost in contemporary models is very similar to the framework initially proposed by Braby et al in the TECEP model, now a decade old. The reader is struck by the evolution, conceptually and methodologically, during this period of the training effectiveness literature in comparison with the cost literature. This may be a reflection of the disciplinary orientation of the model developers, most of whom have been psychologists, but it also may be attributable to the absence of a detailed cost accounting system supporting the improvement of CTEA cost models.

The concepts and methods of cost analyses as applied to CTEA are well established in the literature. The weakness of this literature seems to be in its reluctance to explore production and process function approaches to obtain more useful cost estimates. (Solomon, 1985) The CTEA cost literature reflects an emphasis on the specification of statistical cost functions where the cost per unit of output is described as a function of the resources employed in training. The formal specification of a production function underlying the cost function is rarely addressed. As a consequence, CTEA cost models are limited in what they can say about optimal combinations of resources for different output levels of training.

To address this deficiency, Solomon (1985) suggests an expansion of the financial accounting system data base to provide information on parameters such as resource utilization and capacities and scale of activities. This information would be used in conjunction with improved cost accounting information to determine optimum combinations of factors for different levels of output. Alternatively, activity analysis is suggested whereby a set of related activities are defined in a training process. The resulting process function, comprised of these activities, can be used for attribution and evaluation of costs in the existing training process and may provide the basis for estimating and evaluating costs associated with changes in the training technology.

Very little work of this sort has been undertaken. Solomon refers, for example, to the activity analysis undertaken by the Army Training and Doctrine Command (TRADOC) as a by-product of its effort to develop statistical estimating equations for determining instructor manpower requirements at its service schools. While this suggests a new direction for CTEA cost model development, it does not reject the statistical cost function approach. It merely surrounds this approach with additional information linked to the training production function. Insofar as the statistical cost function approach is concerned, there are several important lessons to be drawn from the CTEA cost literature.

## Specification of Model Objectives

The importance of specifying model objectives is stressed throughout the literature. (Braby et al, 1975; Matlick et al, 1980a) The specification of the cost function will depend on whether the objective is to compare alternative training technologies, to determine the life-cycle cost of a system or technology in relation to its benefits, or merely to appraise the budgetary impact of fielding a new weapon system. CTEA cost analysis is largely focused on the first of these objectives with an eye toward cost minimization.

## Cost Prediction in the Conceptual Stage of a Weapon System

CTEA studies are conducted at all stages of the weapon system life-cycle, but the most important in terms of its cost-saving implications is that conducted during the conceptual stage (DA Pamphlet 11-25 LCMM, 1975; Jorgensen, 1979; Matlick et al, 1980a). It is in this stage that the best potential exists for low cost design modifications of the system to enhance effectiveness and readiness. Design changes at development, procurement, or operation and maintenance stages in response to CTEA normally entail higher system costs.

This theme is expressed in several CTEA models which were developed with this objective in mind. The common problem encountered by these models is the absence of historical cost data for use during the conceptual stage of weapon system development. In the conceptual stage, the source of cost data is frequently the contractor. Some have suggested that the development of a financial accounting data base for CTEA be incorporated into contract requirements.

## Coordination of System Design, Training Development, and Cost Analysis

The literature suggests that predictive CTEA models in the conceptual stage benefit from the close coordination of those who design weapon systems and training devices and those who develop training and conduct the CTEA. (Matlick et al 1980a; TRASANA TEA Handbook, 1980) Coordination among these individuals leads to a better understanding of data needs for CTEA and well-established channels of communication promote the discussion of system design issues and the early detection of problems leading to costly system design changes.

## Cost Prediction Through Comparison-Based Methods

Comparison-based methods offer one approach to overcoming data deficiencies in cost estimation during the conceptual stage of a weapon system or technology.(Klein,1985) This approach calls for the identification of a comparable weapon system, training device, or task to that under development. Subject matter experts familiar with the comparable system or technology are asked to use their experience in projecting the cost and effectiveness of the new system or technology. This methodology uses expert judgment to offset the data deficiencies of cost estimation during the conceptual stage of development. The problem addressed by this methodology is a serious one warranting further investigation of the methodology's potential for predictive CTEA modeling.

## The Financial Data Base

Improving the Army's financial data base for CTEA cost analysis is a critical need as seen from the literature. (Matlick et al, 1980a; Balcom et al, 1984) This issue goes beyond the problems of cost estimation during the conceptual stage of development to include later stages as well. Cost data maintained for budgetary purposes do not always conform to CTEA needs, since the latter exclude resource costs that are common to alternative training technologies and value the resources used at their opportunity cost. The development of a CTEA cost model must keep this constraint in mind. A proposed cost element structure by Knapp and Orlansky (1983) would accommodate data for management and cost-effectiveness analysis by establishing a systematic framework for the cataloging and separation of resource costs.

## Cost Estimation for Computer Assisted Instruction

Computer assisted instruction poses some special problems for cost estimation, primarily in courseware development. Orlansky (1985) reports that courseware development represents a large share of system cost in computer assisted instruction. This includes the development of course materials for use with computer-based devices and the arranging of this information for computer-based control in instruction. Estimation of this cost, particularly in the conceptual stage of system development, requires special expertise due to the unique nature of the technology.

The valuation of time-savings using computer assisted instruction also requires special consideration. The introduction of this technology may result in systemic reductions in training time. Performance standards may be raised and the time-savings used to meet these standards, or classes may simply be graduated in a shorter time period. The latter would result in cost savings which should be acknowledged in the CTEA. However, if the technology results in varying time outcomes for different students with no provision for using the time saved, such as moving the graduate to the next training stage and filling the training slot, then the time-savings should not be considered in the CTEA.

Exposition of CTEA Results

The literature stresses the importance of properly presenting the CTEA results on costs.(TRASANA TEA Handbook,1980). Time should be spent in highlighting the important cost drivers and how changes in these resources influence cost-effectiveness. It follows that time spent by the analyst in estimation should be focused on the important cost drivers. Sensitivity analysis should be employed in the presentation to convey the robustness of CTEA results to the analyst's underlying assumptions.

### Familiarity with Institutional Constraints

The development of a CTEA model and its use requires a working familiarity with the institutional setting in which training occurs Specification of the model and its data requirements demand this familiarity as does the application of the model. The literature suggests that useful applications of CTEA will consider budgetary constraints, existing technologies and resources, individual and institutional biases, and organizational goals and objectives. (Braby et al, 1975; Matlick et al, 1980a; Hawley et al, 1983; NATO Symposium, 1985.)

### Model Specifications Involving Training Devices

An extensive CTEA literature exists on training devices. T e cost of these devices will be driven by their reliability, availability, and maintainability. The cost model specification should anticipate downtime, parts, spares, and repair services. Cost estimates should consider a contractor's performance history and DOD and Army supply routines and schedules.

### Audit Trails

CTEA analyst turnover can be a serious problem to maintaining continuity and consistency in model development and application.

(Matlick et al, 1980a). It can greatly complicate efforts to reexamine earlier decisions in applications. As a consequence, several cost models require the maintenance of an audit trail. (Hawley et al, 1983; Klein,1985). A paper trail of decisions is important even in the absence of analyst turnover as one attempts to reconstruct earlier decisions.

### Generic Models

Several model developers have espoused the development of a generic CTEA model, but the literature suggests that this goal has not yet been attained. (Matlick et al,1980a; TRASANA TEA Handbook,1980) From the training effectiveness perspective, the TDDSS model appears promising, but little specific information is available presently on the cost framework employed in this model. Recent model development efforts have focused on the specification of a cost element structure to improve the relevance, completeness, and comparability of costs among alternative training technologies and to provide a common basis for cost data generation and collection. These efforts are also intended to improve communication among the various organizations concerned with training. (Knapp and Orlansky, 1983; Seidel and Wagner, 1977)

The development of an accepted cost element structure for defense training would represent an important step toward a generic cost model. This step would increase the likelihood that all resources employed in training would be enumerated. Enumeration leads to the valuation of these resources using sound economic concepts. The latter, however, requires the analyst's judgment and further model specification. Determining which resources are fixed and which are variable, for example, is critical to the estimation process. Generic cost models can at best specify the treatment of broad resource classes.

The use of generic models, created in this fashion, will require a higher degree of user sophistication than more specific models tailored to particular training technologies. The latter permits a more detailed specification of the model with a resulting reduction in the need for user discretion.

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