# DESIGN CONSIDERATIONS FOR EMBEDDED TRAINING COMPONENTS

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**ABSTRACT**

Embedded Training (ET) is now a realistic alternative in training systems design and implementation. With the proliferation of embedded computers in military and commercial systems, the capability exists, at generally affordable marginal costs, to bring training to the user in the workplace. However, ET should not be thought of as a total training solution or as a panacea. Not all training can or should be supported by ET. Several roles in the total training system are appropriate for support by ET, however. A decision approach for assigning ET to appropriate roles in the training system is discussed in the body of the paper. In order to attain useful, functional ET, a close and continuous relationship is required among training developers, requirements developers, material system developers, logisticians, and users, for new systems, throughout the system design and development process. The paper addresses some issues which are of paramount importance and concern in this process. In addition to close integration during system development, ET also requires life cycle support, along with the remainder of the system. Some specific issues concerning the logistical support of systems containing ET components are discussed.

## INTRODUCTION

An operational definition of Embedded Training (ET) considers ET to be:

> "...training which results from the use of features intentionally incorporated into the end item equipment (the operational system) to provide training using the end item equipment. Features of ET must include presentation of stimuli necessary to support training, and should also include: (a) performance assessment; (b) feedback consistent with reinforcing correct performance; and (c) record keeping to allow management of individual and collective performance trends, improvements, and deficiencies requiring additional training."(5) [Author's emphasis]

With the incorporation of embedded computer systems in an ever wider variety of systems, both military and civilian, the potential to implement ET on a broad scale--from the copier room to the battlefield--has arrived. However, ET cannot and should not be incorporated into systems on an *ad hoc* or "nice to have" basis. Rather, a full life-cycle commitment to developing, integrating, and supporting ET is necessary.

This commitment extends from the earliest stages of concept development for a new system through the final modification and product improvement of a fielded system. The training developer (TD) is clearly a key player in attaining effective ET. However, the TD must establish and maintain an interchange of information with a number of other players in the system development, fielding, and support processes. These include:

1. The requirements developer (RD) that establishes performance and supportability requirements for the system;
2. The material system developer (MD) that oversees the evolution and development of the system and its fielding;
3. The user, who will employ the system in its operational role; and
4. The logistician (LOG), who develops and programs support and maintenance considerations for the system.

These interfaces are critically important in fielding effective ET. If any of them are ignored or slighted, the risk of not having ET at all, or of having an ET component that does not effectively fulfill training requirements, increases significantly. The TD must assume a more prominent and more proactive role when ET is under consideration than with any other sort of training development. It can be safely said that the ET developer must become one of the key members of the system design and development team in order to assure that effective ET comes about.

Myriad issues have surfaced in the study of ET over the last several years.(1, 4, 6, 7, 8) It is impossible to deal with all such issues in one paper. Therefore, this paper concentrates on three key sets of issues. These are:

1. Identifying appropriate roles for ET in the development of the training system concept;
2. Considerations in integrating ET with the prime item system; and
3. Logistical support issues of paramount importance to effective life cycle support of ET.

These three general issues are critical in the development of effective and supportable training through ET. However, little or nothing is available in the literature or in practice to enable one to effectively consider and deal with these issues. Therefore, they are discussed in the following sections of this paper.

## ET IN THE TOTAL TRAINING SYSTEM

ET is not a universal panacea for training problems. Nor is it appropriate in all training situations, or for all purposes for which training is provided. Research has shown[7] that ET is most appropriate for sustainment of mission-critical, perishable tasks. There are certain other training domains in which ET can also provide a significant element of training support in the context of the total training system. Several distinct training situations, common to many military training programs, are candidates to be supported by ET components. A procedure, usable even in the pre-concept phase of the system acquisition process, has been developed[6] to identify appropriate roles for ET, considering the various likely training situations. This procedure consists of the following steps:

1. Identify likely crew and maintainer positions for the system. This step lays the groundwork for later considering probable operator and maintainer functions, and the appropriateness of ET for each, in various training contexts.

2. Identify functional performance requirements (FPRs) for each kind of crewmember and maintainer. Generic FPRs for various types of systems are available[6] as a point of departure for this process. These are general areas, at a higher level of abstraction than tasks, where training may need to be provided.

3. *Specify which FPRs are to be accomplished* by each kind of crewmember or maintainer. This provides a basis for considering both individual and collective performance, and therefore, training requirements, across crew and maintainer positions.

4. Develop user-system interface equipment suite concepts for crewmembers and maintainers. This assists later extrapolation or projection of the characteristics of tasks that may be performed by each crew or maintainer position.

5. Classify FPRs (for each position) for performance difficulty, perishability, mission criticality, and requirements for collective performance. This assists in the identification of likely training requirements for each FPR, and the later assessment of the appropriateness of various training approaches.

6. Identify training requirements (associated with specific FPRs) and classify them as to needs for hands-on performance, *sustainment training, and collective* training, and possible suitability for inclusion in ET. This step identifies categories of FPRs that need to be considered differentially in later steps.

7. Identify preferred and alternate hands-on training support approaches for each FPR for various training situations. Training situations include operator versus maintainer training, individual versus collective training (for operator positions), institutional versus unit setting, initial training versus sustainment, and task type (for maintainers). This procedure limits itself to dealing only with hands-on training, since it is designed for use very early in the system development process. The flowcharts in Figure 1 are used to evaluate alternatives for various situations. These flowcharts are based on an exhaustive analysis and synthesis of media selection approaches, with a focus on use of various approaches during system concept development. A specific definition of terms used in Figure 1 appears in Table 1.

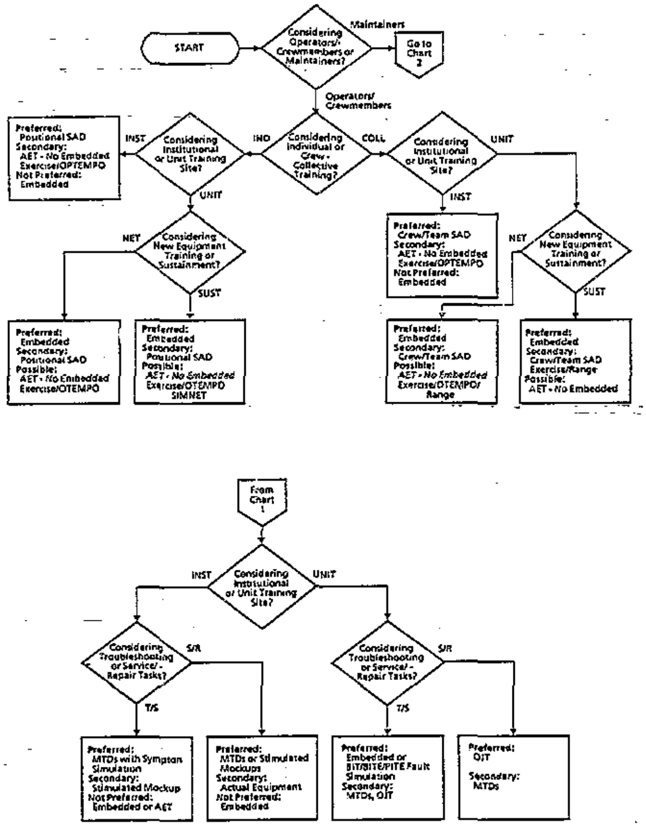


Figure 1. Training concept decision support flowchart

8. *Integrate hands-on training approaches*, by training situation, to develop the comprehensive training system concept. This step aggregates the identified training support alternatives across FPRs

and training situations, to provide an integrated picture of the training system concept developed in the previous steps. Eight different training situations[4] are considered in this process.

9. Document the training system concept and assure appropriate supporting analyses are provided as backup.

This procedure was originally developed during analyses to define training systems concepts for the Army's Armored Family of Vehicles (AFV). It has been subsequently revised and streamlined to serve the needs of the training developer attempting to develop training system concepts (incorporating ET and other alternatives) early in the system concept development process.

## INTEGRATING ET WITH THE PRIME SYSTEM

Conceptually, designing an ET component (from a training point of view) is generally a straightforward, although laborious, process.[8] It parallels the analytic and other procedures required to define a major system training device. Causing an effective ET component to come into being, however, is altogether another issue. The TD must take on roles and responsibilities in the system development process that have not previously been required. The TD must become a full-time player, and a proactive advocate of ET, in coordination with the other players listed above. There are several issues to which close and continuous attention must be exercised throughout system development.[1] These are:

1. **Design team organization.** The TD must play a role in the design team, as an advocate and defender of ET, that is not required in systems where ET is not considered as a major component. There is a continuous need during the development of a system with ET for a close and cooperative relationship between the TD and all other design team members. ET and prime system development should be part of a single acquisition program, to ensure that functional requirements, system hardware architecture, and software architecture can fulfill both operational and training roles.

   The key issue here is to have ET requirements integrated into overall system requirements from the earliest stages of the design process, and to insure their continued integration by awareness of all system design evolutions that could influence the ability to implement ET. The TD, in the role of the proponent for ET, must remain aware of all proposed changes in the operational system, and must evaluate the possible impact of such changes on the ET component. It must be accepted that operational requirements necessarily will come first, but a serious defense of the ET component must take place when needed, to avoid compromise when tradeoff times come, as they inevitably do in all development programs.

   The TD must insure the interfaces and communication channels are in place to make the needs and desires of the ET advocates known to all other players, and exercise those channels as necessary to ensure that ET requirements are not traded off for reasons less serious than the need to meet major operational requirements.

2. **Timing.** A common complaint raised by ET developers is "we were too early and too late." The ET component must be initially conceptualized well before even the first iteration of the system design is complete. However, the ET component design must also evolve with the system design (and the associated tasks).

   This means that the ET developer must attempt, from the very outset of system design, to set aside a portion of the system's resources for ET, consistent with the existing ET concept and requirements at that point in the system life cycle. While this may end up being compromised to a greater or lesser extent later in the development process, the ET developer must strive to have the resources set aside that are needed to implement at least the earliest (and least specific) ET capabilities contemplated for the system.

   This requires a process of insuring that the other players on the design team have the same perspective on the importance and value of ET as do the TDs, and assuring that this perspective continues throughout system development, as the ET concept and design evolves. Again, communication and interchange of information are the keys!

3. **Access to operational software.** This has been a major problem in many ET implementations to date.[2, 3] An ET design will often specify use of portions or features of the operational software in order to conduct training. When design of the operational software is not coordinated with ET design, this frequently becomes difficult or prohibitively expensive to implement. The training provided by the ET component suffers, as a consequence, since ET cannot link into the operational software to provide the required training situations. ET then cannot perform as designed, with consequent degradation of planned training capability, and the need to rely on other training resources to provide the necessary training experiences. This can have significant cost, as well as training effectiveness, consequences.

4. **Physical system requirements.** ET is generally implemented through system computers, storage devices, and input-output capabilities. Yet, most operational systems are designed to provide

only enough processor capacity, storage, and input/output to handle normal system operations.

What then becomes of ET, that is supposed to use these facilities to conduct training? ET will almost certainly require system capacity in excess of operational requirements[1]--in some cases, perhaps even two or three times more. There is no question about where the available resources must go first--to operational capability--yet ET imposes requirements for resources, as well. The answer is to design in sufficient capability to support ET as well as operational software in the baseline configuration, and to protect the "ET budgets" zealously throughout design and system development.

Initial requirements for implementing ET should be weighed against physical layout, weight, volume, and heat production associated with the ET component and the operational system. However, ET implementation may not require as much "additional" hardware as may first be imagined. A key consideration is the potential for ET to share resources with the operational system. For example, if ET and the operational system are not required to function concurrently, then ET can use resources that are normally used by the operational software. This is particularly the case when ET does not need to utilize the actual operational software, or can use a "training copy" of the operational software to create training situations. However, such use may impose additional processing and storage requirements for the system as a whole that will not generally be anticipated by strictly operational software considerations.

These resource allocations and tradeoff considerations must occur early in system design, and be often iterated for ET to "have a chance" in the system development process. The TD must therefore be an activist, and work in a constantly proactive mode, in order to assure an effective ET implementation.

## LOGISTICAL CONSIDERATIONS

In addition to providing effective training, ET must also not detract from the supportability of the system in which it is embedded. This means that ET must be considered during logistical support analysis and planning for the system, as an integral element of the system design. Further, since the training provided by ET will need to be modified and updated during the system life cycle, provisions for this support must be made. And, the use of the prime system for ET in addition to other roles may impose some wear and tear on elements of the system, that could impact reliability. Each of these topics is further discussed below.

### Logistical Planning

ET can generally be thought of as one mode of using the total system, even though ET-based training may not actually use all system components. This means that the TD with ET advocacy must establish still another unfamiliar relationship--in this case, with the logistician. In this role, the TD must ensure that ET-related use of a system is considered when the operational mode summary and mission profiles for the overall system are established. If this is overlooked, reliability and availability predictions for the system may overestimate the actual case.[1]

It appears unlikely that ET will be a major contributor to reliability problems as a system element. Indeed, in some cases, ET may have a beneficial effect on reliability. This is particularly a potential in the case of electronic systems that are not operated continuously. The more the systems are used overall, the higher the likelihood that problems will be detected early. This can lead to early diagnosis and correction of problems, with the result that the system's availability may actually be increased.[5]

The interface between the TD and logistician will require the TD to accomplish certain estimates much earlier in the life cycle than has traditionally been the case. These estimates pertain to how often the ET component is likely to be used, or a proportion of total use time devoted to ET-based training. Normally, training time estimates occur much later in the development process. However, the logistician requires this input very early in the life cycle--as early as concept development--to support operational and organizational planning for the system.

No specific methods for early estimation of training time requiring ET to support logistical estimates have been developed. A recommended approach for the TD is to select a predecessor system that is used in ways similar to the ways the new system is expected to be. Then, the training for the predecessor system should be characterized, with particular attention to the roles potentially supported by ET.[6] Under the assumption that ET usage will roughly approximate the time required for training in those roles, this information can be used to project ET use time. Obviously, this can only be a rough projection, and can easily overestimate ET usage. Nevertheless, it may be better to run the risk of overestimating ET use rates in the interest of having ET considered as an operational mode during logistic planning.

### ET Update Considerations and ET Design

The courseware implemented in any given ET component will change, and will therefore require update and modification over the life cycle of the system. Changes in tactics, doctrine, the threat, the use environment, the user, or other modified factors will mandate courseware updates that reflect these changes. The ET component, and its interfaces with other system elements, must be designed in a fashion that makes this a simple and straightforward process.

The cardinal rule here is never permit the ET courseware to be implemented in line-coded software. Software development and modification is laborious and expensive, and courseware changes should not require changes to the software. Some elements of ET-implementing software obviously will have to be line-coded, to make it possible to implement the ET-based training at all. However, the elements of courseware that have any significant chance of modification over the system life cycle should not be implemented in software. Rather, these elements should be designed in such a fashion that they are implemented as data files, which are used as parameters or input data to control the execution of implementing software algorithms. Also, facilities to make courseware updates straightforward and easy should be provided.

Since ET is computer-based, update facilities should probably include some sort of authoring system or authoring language support, provided to those with courseware update responsibility. Such a system could be conceptually used to update courseware for all of the training devices, ET, and Computer-Based Training (CBT) used for a given system, by using a transparent, common-user-interface authoring front end and common source files, accompanied by appropriate back-end translation software to prepare specific courseware files for each type of device.[1]

A second rule is that the elements of ET implementation that must be line-coded software should be an integral part of the operational system software.[1] This means that the ET-implementing code should be designed into, developed and tested as part of, and modified along with, the remainder of the operational system software. This requires that the functionality of the ET component be defined specifically and early, and communicated to the software developers in time for ET to be integrated into the software design process.

Even a rough notion of what may be required to implement an anticipated ET component should be identified and communicated to system designers as early as possible in the design and development process. As ET concepts and requirements evolve along with the evolving prime item system, these changes must be made known to the software developers. Iteration of requirements definition for ET and assessing related design implications, at least as often as major phases of the acquisition process occur, is a key to making ET happen. A second key (once again) is communication--having effective and appropriate lines of communication between the ET advocate and the design and requirements development teams.

**Reliability and User Interface Hardening**

When a system has an ET component, some parts of the system are used more frequently than when ET is not present. This specifically refers to elements of the user interface--controls and displays used in conducting ET. A problem commonly experienced with training devices that use unmodified actual-equipment user interfaces is that there is much more wear and tear on the interface equipment--especially controls--than the equipment was designed to handle. Reliability therefore suffers, and maintenance needs increase. The same potential problem exists for systems using ET, unless more robust ("hardened") equipment is used for the user interface. If ET causes use of mechanical portions of the operational system (e.g., turret drives, etc.), these may also experience increased wear and possibly increased maintenance needs, as a consequence.

This means that it is wise for the ET advocate to alert hardware designers (as well as logisticians) to this possibility, so that the additional use of affected equipment can be allowed for in design and support planning. Given this information, the designer can select more robust components for the user interface, and the logistician can plan for possibly higher failure rates on user interface equipment that is not "hardened." The potential for reliability degradation is easily avoided by this simple step, but the step must be taken. Frequent reminders of this possibility may also be in order, as the system design evolves during the development process.

**SUMMARY**

Earlier sections of this paper have dealt with several specific topics in the design and development of ET. Here, the basic points underlying all of these considerations are reviewed.

The first point for the ET designer and advocate to keep in mind is to establish and maintain lines of communication with all the other involved players, throughout the system acquisition process. The ET advocate must understand the decisions required of the full design team and each of its members, and prepare and provide the ET-related information needed to impact those decisions. This is important with ET more so than ever before, since ET must be designed into the system from the beginning. Some efforts have been made to retrofit ET into existing systems.[3] Without extraordinary cooperation from the material system designers, this is very difficult or impossible. Once metal is bent and code is written (without ET included), getting ET into a system may be only a pipe dream.

A related point is start early. Information on which to base ET decisions is scarce during early stages of the acquisition process. But, if it is desired to have ET, then some estimate of what it may take to have ET must be made very early in the process. Rough estimates, based on comparisons to systems already in the inventory,[3] may be enough at early points in the design process. But, the estimates must be made and communicated in order for other players to remain aware of anticipated performance and implementation requirements for ET. Also, ET requirements must be included in appropriate acquisition documentation, to ensure that ET is genuinely considered to be "part of the system."

A third point is the need to iterate ET requirements definition and design. The early, rough estimates of requirements for ET (and related implementation requirements) must be followed up by improved requirements statements based on detailed front-end analyses, as soon as sufficient data to perform the analyses are available.[7, 8] During concept development and exploration, a concept of the ET component, including notional candidate training structure and implementation ideas, should be developed and at least conceptually validated. If an exploratory development stage occurs for a system, the ET concept should be refined and tested in a human-in-the-loop or user interface testbed, to validate and refine the ET concepts.

When full-scale development occurs, a full-scale development version of the ET component should be developed as well, and tested as part of technical and user tests. This (required) degree of concurrency between operational system development and training development is relatively unique to ET. However, it cannot be dispensed with, since ET must be designed, developed, and tested along with the prime item system.

A related point is that ET that is developed and tested as part of the system acquisition process may be somewhat different than that ET fielded with the system. It may be necessary to perform incremental testing of ET, including in-plant tests, since it is evolving along with the system. Therefore, some additional effort may be required to conclusively demonstrate the capabilities of ET. This may require developing interim test elements that will not necessarily be part of the final ET component, but are only "test articles."

The final point is that compromise is probably inevitable. The performance requirements of the operational system must ultimately take precedence over all other requirements. However, ET has the potential to contribute to the performance of the overall system through developing and sustaining the performance of the human components of the system. This should be kept in mind as ET, the prime item system, and the remainder of the total training system evolve together. ET should not be a goal in itself, but a contributor to the performance of the total system. By becoming and remaining involved as an integral member of the design team, the TD can effectively advocate and support providing ET for this purpose.

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Table 1

Explanation of Abbreviations in Figure 1

| Abbreviation | Explanation |
| --- | --- |
| Positional SAD | A Stand-Alone Training Device (SAD) used to support hands-on training for a single crew position |
| AET - No Embedded | Training using the actual equipment without Embedded Training capabilities |
| Exercise/OPTEMPO | Conventional, exercise-based training |
| Embedded | Embedded Training capabilities incorporated into an operational system |
| SIMNET | Utilization of networked stand-alone simulators to support hands-on training |
| Crew/team SAD | A SAD used to support training for a crew or subset of crewmembers for a system |
| MTD | A Maintenance Training Device (MTD) used to support hands-on training for maintainers |
| BIT/BITE/PITE | Built-in Test (BIT), Built-in Test Equipment (BITE), Plug-in Test Equipment (PITE) |
| OJT | Conventional On-the-Job Training without training device or ET support |