There are a number of problems which need to be solved before life cycle costing can be fully implemented. Most of these are concerned with standards for estimating the various parameters involved. For example, to arrive at quantities of spare parts needed, an equitable basis must be provided for reliability and maintainability prediction and demonstration. Uniform methods must be agreed upon for arriving at the other costs involved. These are the costs of Supply Management and the total costs of all maintenance and operation actions required.

A potential danger which must be guarded against lies in attempting to refine life cycle costing estimates to the point where more is spent on the costing exercise than is saved by making the proper choice of the vendor. However, let us not lose sight of the fact that DoD is coming to grips with all these problems and the day is coming when many procurements will be made on the basis of Life Cycle Cost. When the time does come let us make sure that we are ready for it.

SYSTEMS EFFECTIVENESS

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INTRODUCTION

Just last week I was asked if Systems Effectiveness was a definable thing, or was it a conglomeration of separate disciplines. The fact is -- Systems Effectiveness is a relatively new title given to a group of related disciplines, all of which affect in varying degrees, the availability of a system to function as intended.

Considering Systems Effectiveness is like considering an automobile. One can describe an automobile as a vehicle designed to transport people, but when we get right down to it, we find ourselves describing the engine, transmission, suspension, brakes, etc. There is no avoiding it. And so, we can define Systems Effectiveness, but we must talk in terms of its components.

The Honorable George E. Foch, Deputy Assistant Secretary of Defense (I&L) recently posed the question: "How best can we -- in Government and industry -- push forward in developing better techniques for improved value without fostering technical specialties and associations that become islands unto themselves?"

The purpose of Systems Effectiveness as an organization is to pull together in a coordinated and integrated fashion these related disciplines which I will discuss in this paper.

Until recently, what now is called "Systems Effectiveness" variously was called "Reliability," "Quality Assurance," and "Product Assurance." All of these titles met considerable opposition in many quarters. Quality Assurance people claimed that reliability was "nothing more than the extension of quality control into engineering." They claimed that reliability belonged in the quality assurance organization. Ten years ago, many companies were so organized. Some still are.

The truth of the matter was, quality control belonged in the reliability organization; for poor quality often results in poor reliability, but poor reliability is not always caused by poor quality. In fact, improper selection of derating or safety factor, poor choice of a part, poor design concept, inadequate testing, to name but a few, contribute to low reliability just as does poor quality.

And so there arose a struggle between reliability and quality control organizations for dominance. An anemic truce was reached with the coining of "Product Assurance." But this proved even more objectionable as it merely implied assurance of a product, obviously meaningless.

After much searching, the expression "Systems Effectiveness" was derived as a suitably descriptive and universally acceptable title. Many Government agencies and contractors have adopted this title. Many more can be expected to join the ranks in the months to come.

In this paper, I will define Systems Effectiveness, discuss its composition, tell why an organized effort is desired, describe its organization, and discuss its program activities.

SYSTEMS EFFECTIVENESS DEFINED

Systems Effectiveness can be defined in several ways. In MIL-STD-721B, the Government defines it as "a measure of the degree to which an item can be expected to achieve a set of specific mission requirements, and which may be expressed as a function of availability, dependability, and capability." One industrial organization (ARINC) defines it as "the probability that the system can successfully meet an operational demand within a given time when operated under specific conditions." But no matter how defined, Systems Effectiveness relates systems performance to specified mission requirements.

SYSTEMS EFFECTIVENESS ELEMENTS

Having previously mentioned reliability and quality control, just what disciplines do comprise Systems Effectiveness? While not all organizations agree in detail, most recognize those shown in Figure 149. I have divided them into major and minor categories. "Major," those which have a direct effect on systems availability, and "minor," those whose effects are less dramatic.

SYSTEMS EFFECTIVENESS DISCIPLINES

MAJOR	MINOR
RELIABILITY	CONFIGURATION CONTROL
MAINTAINABILITY	STANDARDIZATION
QUALITY ASSURANCE	VALUE ENGINEERING
HUMAN FACTORS ENGINEERING	COST ANALYSIS
	SAFETY
	ELECTROMAGNETIC COMPATIBILITY

Figure 149.

SYSTEMS EFFECTIVENESS JUSTIFICATION

The question has been raised -- why are Systems Effectiveness disciplines needed? Why not permit the project engineer/designer to be his own systems effectiveness engineer?

The truth of the matter is -- modern technology has outdistanced the individual designer's ability to provide these specialized services himself.

At the Sixth Navy-Industry Conference on Material Reliability, Mr. Ira G. Hedrick (1) said, in response to the question -- "should the reliability engineer do the designer's job?" that the designer's tasks had become so complex that he was no longer able to perform all functions, such as stress analysis, aerodynamics, and thermodynamics; and just as it was necessary to provide him special assistance in these areas, it was necessary to bolster him up in reliability and maintainability also. Mr. Hedrick said this about six years ago. Had he said it today, no doubt he would have included all systems effectiveness disciplines.

SYSTEMS EFFECTIVENESS ORGANIZATION

Fifteen years ago, it was difficult to interest contractors in establishing any organized reliability effort. In varying degrees they all had Quality Control, often reporting to top management. But reliability, if in existence at all, was treated as a stepchild, usually dispersed within Research or Engineering Departments.

Since in its narrowest sense, reliability relates to Engineering as does Quality Control to Manufacturing, it seemed logical that Reliability too should report to top management. But even today in many organizations, we find the all-important systems effectiveness disciplines of reliability, maintainability, and human factors engineering, either grouped or dispersed, reporting low in the organizational structure.

Almost no industrial organization would think of making quality control (or quality assurance) subservient to manufacturing. For were this the case, delivery schedules and costs would take precedence over quality, and customer dissatisfaction would result.

Just as an effective Quality Control organization can contribute to the delivery of conforming merchandise by being organizationally independent of Manufacturing, the other major Systems Effectiveness disciplines likewise, by being organizationally independent of Engineering, can contribute to the reduction of defective designs which sometimes reach the hardware stage. All will agree that this is the least expensive place where defects can be prevented from finding their way into equipment.

Drawing on experience and on observation of other organizations, I have reached the conclusion that in large organizations, Systems Effectiveness should be both staff and line. The staff, reporting to top management, serves as the policy maker, and as the developer of new and improved techniques. Also it supplies the "how to do" to line personnel, and serves as the technical home to such personnel.

The Systems Effectiveness line personnel are integrated into the engineering and other organizational segments where they function as part of a team. Here, from line management they receive their work tasks -- the "what" and "when."

Small organizations may not be able to justify this arrangement. It may be that only one or two systems effectiveness specialists can be justified. In this case, they may be staff or line, but in either case, they must have direct access to top management.

Unfortunately, many department managers are too schedule and cost conscious, often to the detriment of quality, reliability, and the other systems effectiveness disciplines. It has been said that there seldom is enough time and money available to do things right the first time, but there usually is the second time. How many times have we witnessed the Government (and industry) turn out a poor product, with the "time and money" excuse, only to recall the product, digging up the money (and time) from someplace? It is called "product improvement."

Figure 150 shows a typical contractor's organization having Systems Effectiveness ideally located. It can be observed that each department has its own Systems Effectiveness Group, connecting to the Systems Effectiveness Staff. This scheme should satisfy critics of either staff or line arrangement by providing a reasonable balance of each.

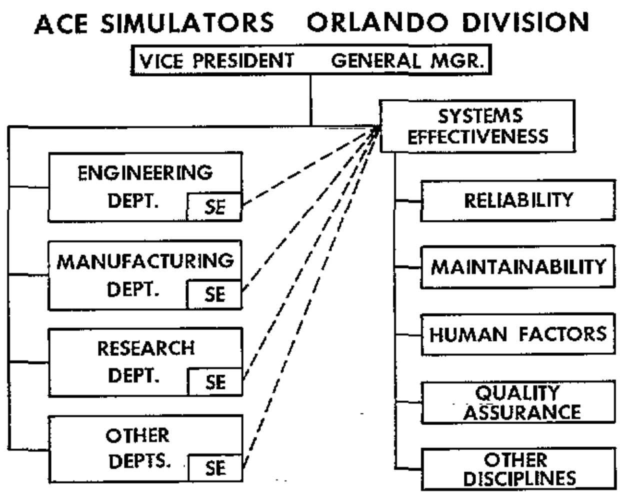

Figure 150. Systems Effectiveness Organization

SYSTEMS EFFECTIVENESS PROGRAM

Of the four major disciplines constituting Systems Effectiveness, perhaps the most critical, and thus the most important is Reliability. It also is the most elusive to achieve and demonstrate.

Most reliability requirements reference MIL-STD-785 "Requirements for Reliability Program." The theme of this document is expressed in its Foreward:

> "The degree of reliability achieved in the development and production of a military system is directly dependent upon the management emphasis received during the project phases."

Proper management emphasis is difficult to achieve when Systems Effectiveness reports low in an organization, as was discussed in a previous paragraph.

MIL-STD-785 provides information concerning both general and detail requirements for conducting a reliability program. It requires that a contractor identify his organization, key personnel, and define their responsibilities and functions. It calls for reliability program reviews at preplanned steps and checkpoints. It requires that a contractor make a numerical reliability prediction, and that he update this prediction at timely intervals. Also, it has several paragraphs devoted to various reliability tests: developmental, environmental, qualification, parts, etc.

In practice, the Government agency provides the contractor with a numerical reliability requirement, sometimes stated as a goal. The contractor is expected to respond with a numerical prediction of the reliability his system's configuration is expected to yield.

To accomplish this, he constructs a block diagram and a companionate mathematical model representative of the system. Into these he applies failure rate data, adjusted by a suitable "k" (correction) factor, and evolves an estimate of his systems reliability.

All this sounds good, but there are serious fallacies inherent which makes one question that this effort is worthwhile.

First there is the goal. This may be stated in any of several ways, but generally in terms of availability, based on the training use cycle. Normally, where a numerical requirement (or goal) is specified, we would expect to see a requirement for a suitable demonstration test. But since this test may require several hundred hours for completion, it is common practice to dispense with it. The ludicrous thing about this is that when related to the total procurement time, i.e., planning, contracting, designing, developing, reviewing, and manufacturing, the demonstration test is a small fraction of the total procurement cycle. Without the demonstration, no one knows if the goal has been met.

Second, there is the matter of prediction. It isn't all bad, but it is greatly abused. When one considers the amount and sources of data used by Life Insurance companies, and the size of population insured, it is easy to see why actuarial prediction techniques provide valid estimates of life expectancy (reliability). Keep in mind that the exact date of birth, and the exact time and cause of death are accurately known and recorded. Contrast this to the absence of similar information about electronic and other parts. Actually, little is known about the curriculum vitae of equipment parts. Yet there are those who would have us believe that it is possible to predict the reliability (life expectancy) of a single piece of equipment. It is no more possible to do this than it is for a remote insurance actuary to predict the life expectancy of a single individual, based on a parts count (one nose, two ears, two eyes, etc.) and utilizing some mystically selected parts failure rates and correction factor.

The "k" (correction) factor is needed to bring the prediction in line with the requirement. I know of a case where a contractor employee predicted a reliability of 72 hrs. MTBF, when the Government specified goal was 75 hrs. He was told to "culture the figures." In other words, this contractor was not about to submit a prediction of less value than specified, and by doing so, risk losing to a competitor.

In another case, a contractor approached the Government with a proposal that he redesign a certain piece of equipment, indicating he could improve the reliability from some unsatisfactory value to 300 hrs MTBF. After go ahead by the Government, during negotiation for an incentive fee, the contractor would support only 15 hrs. MTBF.

Perhaps the solution to the prediction dilemma is to require that its figure, as computed by the contractor, be used as the basis for a guarantee. Each contractor might be required to post a performance bond just as bridge building, and highway construction firms do, or else the Government could withhold the incentive fee. Upon attainment of the goal, the contractor would be paid, on a sliding scale, that part of the incentive earned. Failure to attain the goal might result in his forfeiting the fee in part or in toto.

Predictions based on inaccurate data and on small sample sizes, are valuable only as design analyses tools, used primarily for comparing two or more concepts, for determining potential design weaknesses, and especially for exploring possible needs for redundancy.

Of the other Systems Effectiveness disciplines, maintainability is the closest allied to reliability. Nearly everything said about reliability applies to maintainability. Maintainability has in common the following things: a numerical requirement, block diagrams, mathematical models, requirement for numerical prediction, and demonstration test.

Maintainability can be defined as those traits or product characteristics which are provided in the design process which enable preventive and/or restorative maintenance to be performed according to a predetermined plan and schedule.

Maintainability is measured in terms of MTTR (mean time to repair). More appropriately, MTTR should stand for "mean time to restore."

Maintainability requirements are stated in MIL-STD-470 "Maintenance Program Requirements" (for Systems and Equipments). This document is a close parallel to MIL-STD-785, referenced previously.

Maintainability prediction techniques usually follow MIL-HDBK-472, "Maintainability Prediction." Data used are "average" values at best, and often are estimates. The usual "k" (correction) factor is used to make the theoretical prediction appear in line with requirements.

It would appear that maintainability prediction, in order to be worthwhile, should be based on motion and time study analyses with no "k" factor needed.

A demonstration test designed to evaluate the degree to which a contractor has attained his maintainability goal can be used to demonstrate reliability at the same time, for the total test cycle can be thought of as composed of the summation of times to failure plus times to repair.

Two basic things are required for combined reliability and maintainability demonstration testing. First, of course, is a requirement for the test, and second is a requirement that training devices have incorporated in their design adequate run time meters.

Until recently, no requirement for run time meters existed, but in MIL-T-23991C, we now have such a requirement. Run time meters are a must if we are to collect useful reliability and maintainability data.

Human Factors Engineering can be thought of as one of two major components comprising reliability. One component, equipment reliability, already has been discussed. The second component is concerned with the human aspects of reliability.

Human Factors Engineering is a science, largely a combination of reliability engineering, motion study, and applied psychology. It has to do with matching the equipment design to human capability. Since not much can be done to redesign man (survival of both the fit and the unfit, and unselective breeding have made him what he is), it is necessary to design equipment so that man can manufacture, operate, and maintain it.

Like reliability and maintainability, human factors engineering often receives only lip-service. In fact, David Meister [(2)] in a paper "The Utilization of Human Factors Information by Designers," said the following:

> " . . . . . designers have little or no interest in human factors and usually fail to apply human factors criteria to designs. They do not read human factors handbooks. Design analyses appear to be quite primative, ... "

Furthermore he says:

> "Designers have difficulty in anticipating operational problems . . . . . and are unable to evaluate completed designs."

He continues:

> "Design managers are somewhat more sophisticated in their design analyses than designers, but only slightly so."

Dr. Meister recommends that design specifications emphasize human factors to the same extent that other functional requirements are emphasized.

There are many examples of human factors oversights. One I recall involved two electrical cable connectors on a guided missile erector. Each cable transported different electrical functions, yet the designer (probably a value engineering or standardization zealot) selected identical connectors. To make matters worse, they were installed adjacent to each other. In fact, they were so close together that a man wearing artic gloves could not manipulate either connector!

Human Factors oversights place burdens on the maintenance man as well as on the operator. He is plagued with problems of poor accessibility, items located beyond reach requirements, and often, he is confronted with items too heavy for safe removal. Safe from the standpoint of injury to the man as well as to the equipment from possible dropping.

Poor human factors considerations cause quality control problems also. It may be difficult to perform some manufacturing operations due to inaccessibility, and similiarly, an equal inspection difficulty can result. Often, poor quality is blamed on the manufacturer, when in reality, it actually is the fault of the designer.

Quality Assurance is aimed at preventing manufacturing defects from occurring, whereas Quality Control is aimed at removing those that do find their way into equipment.

Contractors are expected to comply with the requirements of MIL-Q-9858A for most procurements. MIL-I-45208 is used for smaller, less critical items such as piece parts and off the shelf components where only an inspection function is required.

Like MIL-STD-785, MIL-Q-9858A requires that a contractor identify his key QA personnel, define their authority, responsibilities, and organizational position within the company. Quality Assurance must be considered in initial planning, records must be kept, including costs related both to prevention and correction of nonconforming material.

Equipment failures due to quality defects persist. Old familiar defects still occur. The failures seen today are the same type seen last year and the year before. As example, the same kind of diode failures noted in 1957 have occurred each year following.

Device manufactures, relying largely on vendors for parts must assure that these parts are of sufficient quality to meet the equipment reliability needs.

The latest panacea for achieving reliability is the conversion to integrated semiconductor circuits, but failures due to quality defects persist due to sophisticated new processes and extremely small dimensions.

Training device manufacturers must exercise extreme caution when using integrated circuits and other microelectronics. These components have the ability to be more reliable and to cost less than equivalent hardware but it will require more time to resolve the current problems.

Then there are the Systems Effectiveness disciplines I chose to place in the "Minor" category.

Listed first in Figure 149 was Configuration Control, often referred to as Configuration Management. In its broadest sense, Configuration Control encompasses such things as concept, specifications, drawings and the manufactured hardware.

In the concept phase of systems procurement, the concern is that concept is aligned with requirements. This same concern applies to the system as described by specifications and drawings. Finally, we are concerned with assuring that "as made" matches "as procured." All deviations made because of expediencies are documented as to their nature and effect on the system, especially as concerns the logistics phase.

It is easy to understand how the configuration of expensive, large quantity production items are amenable to control. As example, on one guided missile system, where more than $½ Billion was spent on the program, and where production involved tens of thousands of missiles, a precise configuration control system was developed and implemented out of necessity. In this case, the contractor was paid $400,000 to establish the configuration control system.

The question naturally arises, to what extent should the configuration of a training device be accounted for? It is immediately obvious that a device costing perhaps $2 million cannot afford a $400,000 configuration accounting program. Nor would one in total depth be necessary.

Currently, the DOD is placing increased emphasis on Configuration Management. Personnel at NTDC are studying the matter. Sometime in the future, it is expected that the Center will implement some kind of a formal configuration control program, to what depth is not yet decided.

As aspect of configuration control active here at the Center is Drawing Control. NTDC Bulletin 33-1A "Preparation of Engineering Drawings and Associated Lists, Microreproduction of Engineering Data and Preparation of Aperture and Tabulating Cards," is the governing document.

Our drawing control program is concerned with assuring that contractor furnished drawings are made to Government standard format, and are of adequate quality necessary for microfilming and reproduction for reprocurement or device modification.

Although the use of standard parts does not produce a reliability panacea, it often prevents a reduction in reliability due to the use of nonstandard parts, about which little may be known. The use of a nonstandard part complicates the logistic supply system, as such a part, not standard to the Government, and probably not interchangeable with other parts, must be added to the inventory.

We control the use of nonstandard parts and materials through the media of the "Request for Waiver" procedure, whereby a contractor is required to show reason why a nonstandard part or material must be used prior to its use being approved by the Government.

To encourage the use of Government approved parts and materials, the Center has a vigorous Standardization program. This effort has several functions. In addition to the important function mentioned above, our Standardization program is concerned with Military Standards and Specifications, the elimination of nonstandard parts introduced into the military supply system, improving interchangeability through simplification and standardization, and enhancing logistic support.

Recently, NTDC developed and published an updated, fully coordinated, general specification for training devices -- MIL-T-23991C. In the immediate future, NTDC contractors will become familiar with this "C" version of 23991.

Value Engineering forms an important part of the DOD cost reduction program. However, Value Engineering, like Configuration Control, plays its role best where there is a large production follow-on to prototype design. It is difficult to value engineer cost savings where there is little or no production of like items.

There are two contractual methods for obtaining value engineering services. One is by a funded effort, the other is by incentive. It is this latter method by which we obtain VE cost savings in training devices. The contractor gets a percentage of the savings resulting from the VECPs (change proposals) he submits.

NTDC is required to include VE provisioning in contracts which exceed $100,000. These provisions usually include sharing arrangements on the initial contract, and on follow-on contracts which incorporate cost reduction changes suggested by the original contractor and approved by the Government. There also are provisions for sharing collateral savings resulting from cost savings changes.

Although not generally done on training device contracts, it is possible for a contractor to receive a fixed sum of money for performing a designated VE task, as is prescribed in a "Program Requirements Clause."

It is possible for a contractor to increase his profits by about 1% of the overall cost of a contract by actively practicing Value Engineering.

Contractors taking advantage of VE provisions can realize 50% to 75% of savings resulting from accepted Class I changes on initial contracts, and 40% of savings on follow-on contracts for a period up to three years. Subcontractors also can share in VE savings.

In FY '67, DOD contractors submitted 802 VECPs. The total savings amounted to $38.5 million. Eight contractors whose VECPs were approved by the Government received savings from $100,000 to $2 million. But eight DOD contractors having more than $3.3 billion of business did not contribute any VECPs, thus depriving themselves and the Government of benefiting from savings which could have resulted.

Contractors should remember that an earned VE incentive fee is equivalent to profit realized from extra sales.

When one mentions "Safety," many people immediately think of Factory safety -- hard hat, safety shoes, safety glasses, etc. However, when we speak of Safety as a Systems Effectiveness discipline, we refer both to equipment and to human operator and maintenance personnel safety.

Actually, equipment safety largely is a matter of human factors (eliminate possibility of abuse) and equipment reliability. From the standpoint of human safety, we think of safety from electrical hazzards, safety from falls due to slick steps, congested aisles, protruding hardware, etc. It would appear desirable for Government and industry alike to provide some independent scrutiny of these potential hazards as a way of increasing equipment availability by reducing equipment failures from human abuse, and from human lost time due to accidents.

Electromagnetic Compatibility is a new discipline (so recognized by the EIA at its recent Chicago workshop) which is of increasing importance in training devices. This is due mainly to the increasingly congested radio frequency spectrum resulting from the development of electromagnetic radiating equipments. The problem of obtaining new frequencies has become so acute as to result in national and international controls of frequency allocations.

As a result, it has become necessary to require that frequencies assigned to training devices be controlled to assure that interference existing between equipments be kept to a minimum.

Since most electronic equipment is capable of generating and radiating electromagnetic energy, it has become necessary to consider the geographical area where each training device will be located so as to minimize possible interference between it and other equipments.

It is now required that an "Application for Frequency Allocation" be sent to the Chief of Naval Operations for all training devices known to radiate electromagnetic energy. Both the intended frequency and the geographical location must be specified.

In all cases, it may not be possible to assign frequencies at the initial stage of device development. In such cases, the contractor must furnish the Center with information regarding the spectrum of frequencies to be emitted or received so that application can be made and approval obtained before development advances too far.

In summary, Systems Effectiveness, as a descriptive title of the disciplines discussed in this paper, appears to be here to stay. Careful consideration of the application of these disciplines, both by Government and contractor, is required in order that effective systems can be delivered economically and timely to the user.

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MOTION SIMULATION FOR FLIGHT TRAINING

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Discussions concerning motion simulation in operational flight trainers generally attempt to evaluate the value of motion simulation in terms of training transfer and the amount of flight time required to bring groups trained without motion to the same performance level as those trained with motion. This paper is part of a study done to develop criteria for developing the range of motion required and the washout rules for braking the motion once it was initiated. This portion was a literature search concerning comparative studies of simulations with and without motion where the goals were not training but were usually oriented to some other goal.

The results of these simulator studies will be briefly listed, with more detailed discussion deferred to a later part of this paper. They are as follows:

1. Motion cues enable the pilot to control an unstable vehicle, whereas without motion, he loses control.
2. Motion cues enhance prompt and instinctively correct control inputs.
3. Re-stabilization of a stable vehicle after a roll-rate disturbance was twice as fast with motion cues as without them.
4. Control is better with both visual and motion cues than with visual cues alone.
5. Roll control in turbulence is very much better if motion cues are present.
6. Motion cues raise the pilot's response frequency.
7. Roll control at low frequencies is many times more accurate with motion cues than without them.
8. In controlling an unstable vehicle, the pilot uses variable control lead in accordance with sensory inputs (visual and motion).
9. Control error at higher frequencies is much less with visual and motion cues than with visual alone.
10. Motion cues are more closely coupled to the pilot than are visual cues.