A Deterministic Model for Cost Effectiveness Analysis of Avionics Support Programs

Richard A. Navarro* and James W. Smith†
McDonnell Aircraft Company, St. Louis, Mo.

A mathematical model which calculates cost-effectiveness indices for avionics support programs has been developed and implemented. Analyses are based on factors which include 1) the avionic subsystem's supportability, 2) the test philosophy, and 3) the test equipment design and manufacture. A rating factor is derived which represents the quantified interrelationships among these factors and the associated requirements and logistics influences. Direct calculation of costs, manintenance times, equipment capability and performance, and spares factors are provided. An effectiveness factor, based on a statistical analysis of the performance characteristics of the support equipment, is generated. This factor is used to modify the rating and cost values: long- and short-term cost effectiveness indices are calculated. The model has been fully implemented and is presently in use on McDonnell Aircraft Advanced Design efforts.

Introduction

THE order-of-magnitude increases in the costs and complexities of recent avionics hardware have significantly affected the associated support equipment. This effect, coupled with the fact that logistics and operational costs tend to far outstrip initial procurement costs, led to the realization that future support programs, based on Aerospace Ground Equipment (AGE), On-Board Checkout (OBC) or a combination thereof, must be optimized with respect to cost-effectiveness.

Optimization can best be achieved if the various support philosophies and hardware being considered are evaluated in light of performance, initial costs, over-all logistics effectiveness, and over-all program costs. Among the diversified considerations involved in this multifaceted problem are 1) the analysis and optimization of both concepts and hardware; 2) the need to analyze each subsystem's requirements rather than attempting to apply a generalized criterion; 3) the effect support equipment has on the aircraft subsystem's operational reliability; 4) the requirement for an optimum mix of inventory, general purpose, and peculiar support equipment; and 5) the rate at which the logistics state-of-the-art is changing.

The requirement for highly competent, logistics-management direction has been generally recognized for some years. Previous attempts to develop a universal management tool or scheme include 1) MIL-STD-9412, AFSCM375, WR-10, WR-30, and AR-10[1–4] sequences of management specifications developed by the USAF and USN, respectively, and 2) the SAMSOM I and II, PLANET, LCOM, and VALUE II models[5–9] developed by RAND, the USAF and USN. Neither these, nor any other known military or industry attempts, entirely satisfied McDonnell's specific requirements for support system program and hardware optimization. Accordingly, we initiated an extensive in depth study program with investigations ranging from an analysis of the thought processes involved in program-decision formulations to consideration of highly-sophisticated mathematical modeling and evaluation techniques. We concluded that although no one satisfactory solution presently exists, the disciplines associated with mathematical modeling offer the most promise since mathematical models provide a systemized basis for logically analyzing decision problems. Presented with these conclusions, McDonnell AGE Engineering management decided to develop and implement a specialized mathematical model that would enable management and engineering to carefully evaluate subsystems, determine the proposed testing techniques, and select the best test hardware.

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* Design Engineer. Member AIAA.
† Senior Group Engineer. Member AIAA.

Approach

In general, application of a mathematical model to any support program meets with a level of success that is directly proportional to the model's fulfillment of the following criteria: 1) it must utilize data which is readily available in all contract phases; 2) it must be simple and usable to promote confidence and lower the probability of error; 3) it must be flexible and adaptable to changing technology; 4) it must be understandable, workable, and able to "live in the field" with the project engineers and analysts; and 5) it must, above all, accurately represent the programs to which it is applied.

During our exploratory investigations, it became apparent that many existing logistics models exhibit shortcomings, when measured by these criteria, partly because they are used for tasks other than those for which they were developed. To preclude any change of this "develop the model and then shape the results of our problem" situation, development of our model started with an analysis of the problem areas. The results required were then established, and progress continued towards the required input data. This approach provided us with a simple, rapid, and responsive test-equip-

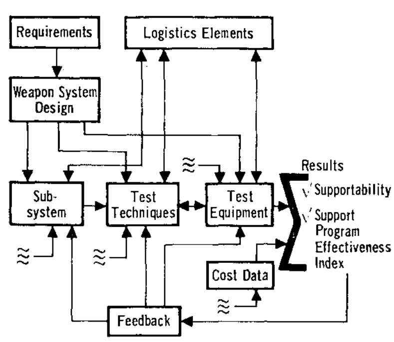

Fig. 1 Basic model.

ment concept and hardware-oriented model which produces outputs directly meaningful and applicable to support programs management.

The major steps undertaken in the development of the model were 1) determination and definition of the types of outputs which would be most valuable in attaining our goals; 2) identification of input parameters with suitable data content to yield the outputs; 3) determination of the model type, format and structure, and development of the model logic; 4) development of the computer program and associated software (data and output) provisions; and 5) validation using known McDonnell F/RF-4 subsystem data.

Discussion

The primary purpose of the model was to analyze a support program in light of the major program considerations, program performance and over-all cost. Therefore, the generated outputs that would be most useful would be measures of the degree-of-optimization of a subsystem/support-equipment package relative to the initial acquisition and life-cycle time periods. To attain this objective, the outputs were established as functions of the Supportability Index (SI) which is a measure of the initial effort required on a program, and the Support Program Effectiveness Index (SPEI) which is a measure of the total life-cycle effort as a function of the effectiveness of the program. These indices were then defined by equations of the following form: SI = [(time × dollar factor) + price]xR_f; where time = total direct and indirect maintenance time/month (manhours), dollar factor = cost per maintenance manhour (including overhead), price = total nonrecurring costs and the recurring costs for the initial buy, R_f = a qualitative rating of the support system's merit. SPEI = [K × (time × dollar factor) + price]xR_f/effectiveness where K = operational life, in months, time = total direct and indirect maintenance time/month (manhours), dollar factor = cost per maintenance manhour (including overhead), price = total AGE nonrecurring costs and recurring costs for the entire program, R_f = rating factor, effectiveness = a measure of the ability of the support program to perform its intended tasks.

Following selection and definition of the major outputs, structure of the model logic was considered. The definitive nature of the outputs, coupled with the desired long-term cumulative-effect calculations, logically pointed to development of a deterministic model. Further, the deterministic format offers important advantages in usability and efficiency. Thus, despite current trends toward increased use of simulation and Linear Programing (LP), we proceeded to establish the logic and major elements of our model along deterministic lines.

System Rating

A major element of each output is the qualitative rating of the particular AGE program being evaluated. To provide a means of performing this rating, it was convenient to establish a factor which would serve as a figure-of-merit indicator. The system Risk is such an indicator, and the first section of the model is devoted to this calculation. The Risk may be thought of as either a simple rating, or, more correctly, as a normalized indicator of the likelihood that the element being evaluated will tend to be better or worse than would be expected (i.e., Risk). A program is considered to be affected by three major influences: the Flight System, the Test Technique, and the AGE Design and Manufacture (Fig. 1). The Risk factor is a mathematical combination of these major influences. The particular values are derived through a "detail" level combination of data inputs which are, or are measures of, selected, representative, quality indicators. All of the data are quantified and then converted to Risk factors based on the deviation from predetermined nominals and the functional significance of a given change from these nominals. (This double-step calculation is performed because, 1) an n percentage change in variable A may be far more significant than a like percentage change in variable B and 2) an m percentage change may have a different significance at varying deviations from nominal). (Fig. 2). The factors are then combined to yield the Risk.

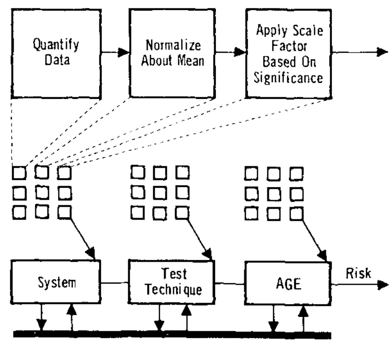

Fig. 2 Risk factor development.

During development of relationships to calculate the Risk, it became obvious that selection of the elements of the data set was of primary importance. The data had to be available, nonsubjective, universally meaningful, and contain the necessary information content. The final data-set determination was accomplished by committee to eliminate bias: determination of relative importance rankings and the functional relationships was based on anticipated changes in the state-of-the-art and extrapolation from McDonnell experience.

Life-Cycle Cost

The second major element in the calculation of the two output indices is the program Life-Cycle Cost. This section of the model computes the sum of the procurement, ownership, and operational costs. Included in the ownership and operational costs are direct and indirect maintenance costs associated with service, test, and repair. Calculation of the maintenance costs comprises a major portion of the total logic.

These two major elements, Risk and Cost, are combined to form the Supportability Index.

Effectiveness

The third major element in the model is the equipment "effectiveness." The effectiveness is based on the AGE's ability to perform its intended task. To provide a performance measure for organizational level (flight line) equipment (either AGE or OBC), certain of the data are used to calculate the probability that, using the equipment being evaluated, the flight equipment will be within specification. The derivation of this calculation is based on the assumptions that testing is cyclic, flight equipment is operational and hence can fail while under test, and all equipment fails exponentially. The derivation considers utilization, repair time, and both perfect and imperfect test.[10] The probability that the flight equipment is within specification (hence, in operable condition) at any given time is calculated for varying support cycle durations. The maximum of the calculated probabilities is used as an indicator of the AGE's highest capability, and, hence, is the required performance or effectiveness.

To provide a performance measure for field level (shop-type) AGE (either specilized or integrated), a more mean-

Table 1 Support Equipment Cost Effectiveness Model (SECEM) typical results summary

Semiautomatic flight line age without preflights and postflights	BITE without preflights and postflights	Concept under study	Semiautomatic flight line age with preflights and postflights	BITE with preflights and postflights
$ 360,000	$ 317,000	Supportability index	$ 381,000	$ 318,000
3,911,000	3,053,000	Support program effectiveness index	45,015,000	3,833,000
1.0085	1.0011	Final rating factor	1.0085	1.0011
		Costs and factors		
$ 335,000	$ 255,000	Nonrecur cost	$ 335,000	$ 255,000
357,000	317,000	SI cost	378,000	318,000
315,000	918,000	Total recur cost	315,000	918,000
1,190,000	0	Related logistics cost	1,190,000	0
3,594,000	2,909,000	SP cost	41,373,000	3,653,000
3,625,000	2,912,000	SP cost index	41,725,000	3,657,000
0.9269	0.9540	Effectiveness	0.9269	0.9540
0.15	0.14	MMH/flight hour	3.27	0.21

ingful indicator than the aforementioned is the probability that an incoming piece of flight equipment will be delayed because of the lack of an available piece of AGE; this is a measure of the AGE's ability to handle the workload for which it is intended. The probability calculation is based on the assumption that arrivals to the shop are essentially a Poisson process. The probability calculation then reduces to a classical queue problem. The queue problem considers the shop to be, relative to each subsystem, a single waiting-line, multiple-channel process. The servicing rate afforded by the shop is derived from the equipment capability, number of parallel channels, equipment reliability, equipment downtime (for test and repair), and subsystem repair time.[11,12]

These elements, and the calculation of these output indices, comprise the largest portion of the model. The following briefly describes how the model works.

Basic inputs, such as Subsystem Complexity Parameters, Test Technique, Subsystem and Support Equipment Vendor ratings, and Design and Manufacture factors, are quantified and then processed to yield three area Risk factors (for direct observation) and a single major Risk factor which properly integrates the effects of all inputs. The Risk factor is combined with cost information, maintenance times, and integrated logistics elements such as spares and facilities. A value for equipment effectiveness is calculated, and the final outputs are generated.

The previous has been a discussion of the major sections of the model and their interrelations. However, many significant provisions of the model have not yet been mentioned; they comprise the unique considerations which render the model usable and capable of meeting the established criteria.

Among the unique aspects of the model are 1) an extensive data bank for drawing replacements for missing data items; 2) complete time calculations to provide an accurate maintenance-effort value for the section of the program being evaluated; 3) an experience calculation that considers improved manpower capabilities as a function of time; 4) a spares level-confidence factor calculation which adds minimum spares costs as a function of confidence required and support posture being evaluated; and 5) a control subroutine which allows integration of various support levels into an over-all program.

To apply the basic model during early phases of a support program, actual values are replaced with extrapolations from historical data and with estimates. To provide an otherwise unobtainable level of consistency, a data bank is incorporated to provide necessary estimates as a function of the actual values available. Thus, a complete and uniformly-correct data set is provided.

To generate an accurate maintenance value, the model calculates the total program maintenance time expenditures based on factors including total scheduled test time, unscheduled test time, repair time, harmonization time, time lost due to incomplete fault isolation, and AGE maintenance time; calculations are for long-term average demands based on average time per task, utilization, and reliability figures. The time calculations are based on the mean times to perform basic tasks, and on input data such as number of tests and physical configuration. Task times are modified by an exponential learning curve which is shaped by the subsystem's complexity and the technical difficulty of the average job to be performed. The time lost due to incomplete isolation, a calculation peculiar to this model, is based on the fault isolation capability of the equipment, mean man experience, subsystem complexity, and an applicable exponential learning curve. This calculation was generated to provide consideration of the impact of incomplete or imperfect testing.

To evaluate a program's direct affect on spares provisioning, a routine which calculates minimum spares demands is incorporated. This routine is based, as in the previous case, on demands being a Poisson process. A distribution is formed about the mean (steady-state) spares requirement, and the total spares for a desired confidence of "no stock-out" is computed from the distribution's mean and standard deviation.[11,13]

The basic model establishes the desired output for a single given maintenance level. However, evaluation of an interrelated multilevel situation may be important, particularly when a base-self-sufficiency, an automatic test equipment based depot, or similar study is required. A subprogram, written to meet the requirement for level integration, is basically an augmentation of the main model with a looping routine. Control is exercised by means of a Field "Not-Repairable-This-Station" (NRTS) rate and a "Type Cycle" switch which together provide complete and accurate representation of any type multilevel, variable-mix maintenance philosophy. Among those elements which are considered are pipeline times, delays, repair capabilities, and shipping factors.

By means of feedback techniques, the model can be used to provide guidance in the optimization of a given subsystem support program. This is accomplished by evaluating the relative changes to the indices affected by incremental changes to input factors. This subroutine makes incremental changes to selected inputs, varied one at a time, modifies any other related data, and then senses the degree of optimization achieved. This step-wise process continues until the particular rating factor reaches a level past which further improvement would be impracticable, or until an incremental input change no longer yields significant output optimization. The subroutine then picks the inputs that effected the highest degree of optimization, varies these inputs in sets, and records the improvements to the indices.

Table 2 Support Equipment Cost Effectiveness Model (SECEM) results summary, parametric MTBF vs test technique analysis: test technique[a]

MTBF, hr	Semiautomatic hot-mock-ups	Semiautomatic test sets	Manual hot-mock-ups	Manual test sets
1000	3,300,000	8,000,000	2,300,000	4,700,000
500	3,400,000	8,100,000	2,700,000	5,300,000
200	3,500,000	8,200,000	4,400,000	9,900,000
50	3,800,000	8,400,000	13,200,000	22,100,000

[a] Numbers shown represent Support Program Effectiveness Indices for four test techniques as applied to a particular class of 2 LRU avionics subsystems.

Implementation

Implementation of the Aerospace Ground Equipment Subsystem Supportability model entailed the following developmental actions: 1) development of a workable computer program to perform the types of logic, data manipulations and calculations, and report generations; 2) development of a usable and comprehensive data collection system (a set of question-form sheets or equivalent); 3) development of output evaluation and reporting methods; and 4) validation of the model using F/RF-4 data.

Equations and logic for the Supportability and the Support Program Effectiveness Indices were written in the form of logic/information flow diagrams which were translated into a FORTRAN IV Language program. The model provides, as a minimum, the following outputs: 1) Supportability Index, 2) Support Program Effectiveness Index, 3) effectiveness, 4) each major rating factor, 5) each major time factor, 6) maintenance-man-hours-per-flight-hour.

Using the CDC 6400, under control of the Hybrid Chipawa compiler and the SCOPE 2.0 executive, compilation and execution of an analysis case requires less than 25,000 core locations and only seconds of operating time.

A form sheet was devised to collect and handle the model's required input data. The model user is requested to insert a value for each input in accordance with specified instructions. The questions on these sheets were phrased to avoid confusion and, thus, eliminate interpretation errors; numerous examples were included for clarification. These form sheets are considered to be an essential part of the program, since the authenticity of the computer results is dependent on the correctness of the input data.

During the model's initial development phases, all major elements of F/RF-4 electronics subsystems support were evaluated. The output data from these runs were compared to the in-house experience on these systems and, thus, used to verify and refine the model. While the form of the model outputs are not directly compatible with the data which were recorded, the outputs of the finalized model exhibit a highly satisfactory level of conformance to actuals.

The finalized, implemented model calculates Supportability (initial effort) and Support Program Effectiveness (long-term effort) Indices that are inversely proportioned to the degree of optimization of the subsystem support program, i.e., the better the program the lower the index. (It should be noted that these outputs are indices, and, though, established with cost as a baseline, they are relative figures-of-merit, and are not to be considered actual cost figures.) (In addition, the model calculates "AGE Cost Per Unit Time Available" and "AGE Cost Per Subsystem Failure" figures for each AGE item; these values are of special importance in evaluating integrated or general purpose AGE.) Selected input data and output parameters for two subsystem support programs, shown in Tables 1 and 2, illustrate the workings, capabilities, and merits of the model.

Conclusions

The resulting model provides program management with a tool for evaluating alternate concept and hardware elements in terms of quantities which have easily-assessible values, and also offers great promise as a means of assuring the attainment of optimized systems support. It is a useful tool for decision making concerning support programs, considers all pertinent factors without inserting prejudice, and provides a common baseline to guarantee consistent and valid evaluations.

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