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LIFE CYCLE COST - TECHNIQUES AND APPLICATIONS

FOREWORD

The complexity and cost of military aircraft has inexorably increased. In real terms, the unit cost of military aircraft has grown by an average of 8% annually since World War II. There is a direct connection between the initial production cost and the cost of development and of producing spares and repairs. Therefore a potential by-product of the growth in investment costs is an increase in support costs. This trend is emphasized by the fact that the increasing complexity, which drives up production costs, also tends to have an effect on reliability, further raising support costs (Reference 1).

Life cycle cost (LCC) is used in the decision making process to evaluate and select equipment offering the most cost-effective solution to meet a defined need.

Support costs can range from being equal to, or many times greater than the initial purchase costs; thus awareness of the whole life cost of equipment before making major procurement decisions is required. This is accomplished through the use of LCC techniques whereby the cost profile of equipment is built up and refined as cost data become available. These techniques address LCC issues including supportability, performance, and manufacturing cost for the following considerations (Reference 2):

a. Provide justification for "spend to save" decisions
b. Enable decisions to be better informed, in particular the determination of initial requirements
c. Allow the impact of different levels of reliability and maintainability (R&M) to be measured to facilitate trade-off decisions with other priorities
d. Enable competing proposals to be evaluated
e. Allow for evaluation of alternative design options
f. Enable the program to be monitored more effectively

Life cycle costing requires a discipline that uses systematic costing methods presented in a consistent manner over the projected useful life of a program.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

1. SCOPE:

This SAE Aerospace Recommended Practice (ARP) describes the concept of life cycle costing with emphasis on LCC techniques and applications as applied to the phases of the program cycle. These phases are:

a. Conceptual studies, research, development, test, and evaluation (RDT&E)
b. Investment, or procurement
c. Operating and support (O&S) or in-service
d. Disposal of systems, equipment, and services

Cost elements, estimating techniques and other factors which have a bearing on LCCs are described; including use of cost estimating relationships (CER), simulation techniques, and "top-down"/"bottom-up" approaches. Consideration is also given to:

a. Risk and uncertainty assessments
b. Impact of economic variations including inflation, interest rates, and exchange rate variation
c. Adoption of discounting techniques when undertaking investment appraisals

The use of tailored LCC models is preferred since there is an advantage in adopting a range of approaches particularly for the prediction of the costs of future technology and estimates of uncertainty which are specific to the aerospace industry.

1.1 Purpose:

This document supplements the general guidelines contained in AIR1939. The purpose of this document is to present an overview of LCC techniques and applications during the procurement process for defense related equipment. This document provides a typical "global" LCC element breakdown structure which is aircraft systems related; while a companion document, ARP4294 provides a detailed scheme for a cost element breakdown structure specific to propulsion systems.

LCC techniques provide a sound basis for cost benefit analysis. Although specifically aimed at the military procurement process, the recommendations contained in this document can apply to commercial procurement. The use of LCC analysis during the procurement process increases effectiveness of program evaluation by aiding decision making and providing a mechanism for transferring information on a common basis.

2. REFERENCES:

1. R.N. Gregory, "The Place of Support Cost Estimates in Initial Procurement Decisions", Proceedings of Royal Aeronautical Society Conference, (November 1989)

2. HMSO, National Audit Office Report, Ministry of Defence: Reliability and Maintainability of Defence Equipment, (February 1989)

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3. AECMA, Life Cycle Cost Perspectives Military Aircraft Applications, (October 1987)

4. R. McNally, "Life Cycle Costing - The Contractor's View", Government Contracting Review, (Summer 1987)

5. SAE, ARP4294 Aerospace Recommended Practice, Data Formats and Practices for Life Cycle Cost Information

6. D.W. Daniel, "Life Cycle Costing: Concepts, Problems Structures and Data Bases", US Society of Automotive Engineers, Technical Paper Series 861786, (1986)

7. Defence Scientific Advisory Council, "Report of the Working Party on the technical risk assessment of advanced technology on large projects", Unpublished MOD Report, April 1988

2.1 SAE Publications: Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

ARP4294 Data Formats and Applications for the LCC of Aircraft Propulsion Systems

2.2 Acronyms and Abbreviations:

AECMA	Association Europeenne Des Constructeurs De Materiel Aerospatial
AIR	Aerospace Information Report
CALS	Computer-aided Acquisition and Logistic Support
CER	Cost Estimating Relationship
CIP	Component Improvement Program
DCF	Discounted Cash Flow
DSAC	Defence Scientific Advisory Council
EFH	Engine Flying Hours
FOL	Fuel, Oil and Lubrication
HMSO	Her Majesty's Stationery Office
IA	Investment Appraisals
ILS	Integrated Logistic Support
LCC	Life Cycle Cost
MTBF	Mean-Time-Between-Failure
NAO	National Audit Office
NPV	Net Present Value
O&S	Operating and Support
PDS	Post Design Services
R&D	Research and Development
R&M	Reliability and Maintainability
RDT&E	Research Development Test and Evaluation
RPE	Relative Price Effect
SAE	Society of Automotive Engineers
SFCA	Specific Fuel Consumption Actual
SL	Sortie Length
UPC	Unit Production Cost
WBS	Work Breakdown Structure

2.3 Definitions:

ACQUISITION COST: The primary investment, being the sum of the total development cost R,D,T&E and the investment cost of the system.

NOTE: R&M have a strong influence on LCC; there exists a two way relationship with acquisition cost and a subsequent effect on the support and unavailability costs.

AVAILABILITY: The ability of an item (under combined aspects of its reliability, maintainability and maintenance, and support) to perform its required function at a stated instant of time or over a stated period of time.

BASIC RESEARCH: Research work in the design concept stages of a system project prior to project definition. It includes theoretical studies and new technology development.

CAPITAL INVESTMENT: Any capital investment in manufacturing or production equipment (including, where appropriate, dedicated software), which is not amortized in the unit production price or included in the contractors' overheads.

COMPONENT IMPROVEMENT PROGRAM (CIP) COST: Total system CIP cost (including software) over the life of the aircraft system. It includes design, fabrication, and test costs associated with component improvement, beyond the original performance level, once the aircraft system is in production.

COMPUTER-AIDED ACQUISITION AND LOGISTIC SUPPORT: The strategy aimed at using digital techniques to integrate technical information flowing from digital systems to facilitate the design, development, manufacturing and support of aircraft systems. It implies the transition to a near paperless design, manufacturing and support environment.

CONCEPTUAL STUDIES COST: The sum of all contractor and government funded costs required to complete the feasibility studies and subsequent definition of any system or equipment conceived in response to meet a mission requirement. These include project related research, theoretical studies, hardware, material, tests, tooling and other supporting activities (e.g., LCC and integrated logistic support (ILS) studies).

CONFIGURATION MANAGEMENT: The process that identifies functional and physical characteristics of an item during its life cycle, controls changes to those characteristics, provides information on status of change action, and audits the conformance of configuration items to approved configurations.

CONTRACTOR MAINTENANCE COST (4TH LEVEL): Comprised of the direct labor costs and all materiel costs, including the value of any customer supplied spares and the costs (labor, material and overheads) of repairing spares together with, if applicable, any transport costs and overheads including any charges made by the contractor for maintaining support teams at all lines.

2.3 (Continued):

COST ANALYSIS: A systematic procedure for estimating the aggregate cost of a system/equipment, and for comparing the costs of alternative systems in order to determine the relative economy and effectiveness of the alternatives.

COST EFFECTIVENESS: A comparative evaluation derived from analyses of alternatives (actions, methods, approaches, equipment, aircraft systems, support systems, force combinations, etc.) in terms of the interrelated influences of cost and effectiveness in accomplishing a specific mission.

COST ELEMENT: The lowest level identified cost for a given LCC analysis. A cost element is further broken down into variables, rates, factors, or constants related mathematically which produce a money amount corresponding to an aspect of the product under investigation.

COST FACTORS: A cost per unit of resource; hence a value established on a per unit basis which, when multiplied by the number of units or program factor, yields the estimated cost.

COST MODEL: An ordered arrangement of data and equations that permits translating physical resources into costs. A mathematical device used to develop estimates and output formats for presentations. The model consists of an input format to specify the problem; information, including both system description data and estimating relationships; and an output format.

COST TRACKING: A process which collects and evaluates data in determining the reasons for variances between successive cost estimates or between planned or projected versus actual costs.

DEVELOPMENT AND VALIDATION COST: The cost of all engineering effort, including theoretical studies and design, hardware, tooling, rig testing, management and other supporting activities including LCC and ILS considerations, to transform the results of conceptual studies into design proposals suitable for full scale development.

ECONOMIC ANALYSIS: A systematic approach to the problem of choosing how to employ scarce resources and an investigation of the full implications of achieving a given objective in the most efficient and effective manner. The determination of efficiency and effectiveness is implicit in the assessment of the cost-effectiveness of alternative approaches.

EQUIPMENT: Refers collectively to an item, component, or subsystem procured for installation in a system or to support a system.

EQUIPMENT DEPRECIATION: The notional loss of monetary value ascribed to equipment dedicated to the system, by virtue of its age.

EQUIPMENT MAINTENANCE COST: Labor and material costs incurred in order to maintain the equipment dedicated to the system in a serviceable condition.

2.3 (Continued):

EVALUATION PROGRAM COST: The cost, if it occurs, of any system evaluation program subsequent to development. The costs may arise either intra/extramurally.

FACILITIES COST: The monetary value ascribed to buildings and equipment dedicated to the system during the Investment phase following full scale development which are associated with setting up a viable manufacturing process capable of sustaining full scale manufacture.

FUEL, OIL, AND LUBRICATION (FOL): All ground running, testing and mission fuel, oil, and lubricants consumed by the fleet during the total O&S phase of a program.

FULL SCALE DEVELOPMENT: All development work on the system subsequent to basic research. It is the work required to bring a system through development to evaluation. It includes design, analysis, development, testing, and management.

INITIAL SPARES PROVISION: The spares purchased to enable start up of the system covering up to two years of base operation for military and six months for commercial operations.

INITIAL SUPPORT COST: The cost incurred by having the system supplier provide maintenance coverage of the new system for a defined period after it has become operational.

INITIAL TOOLING: The initial package of tooling (including software where appropriate) to establish and maintain production of the system as required.

INITIAL TRAINING: The initial training in the new system for operators and maintainers provided by the contractor.

INTEGRATED LOGISTIC SUPPORT (ILS): The management and technical process through which supportability and logistic support considerations of systems/equipment are integrated during the early phases of and throughout the life cycle of the program and all elements of logistic support are planned, acquired, tested, and provided in a timely and cost-effective manner.

LEARNING CURVE: The cost/quantity relationships for estimating costs of equipment. Generally used to predict or describe the decrease in the cost of a unit as the number of units produced increases.

LOGISTIC SUPPORT ANALYSIS: A structured process which includes actions to define, analyze, and quantify logistic support requirements, and to influence design for supportability, through system development.

MAINTAINABILITY: The ability of an item, under stated conditions of use, to be retained in, or restored to, a state in which it can perform its required functions, when maintenance is performed under stated conditions and using prescribed procedures and resources.

2.3 (Continued):

MAINTENANCE COST: The cost of all actions necessary for the retention of the system in, or restoring it to, a serviceable condition. It includes the cost of embodying modifications.

MEAN-TIME-BETWEEN-FAILURES (MTBF): For a particular interval, the total functioning life of a population of an item divided by the total number of failures within the population during the measurement interval. The definition holds for a time, cycles, distance, events, or other measures of life units.

OPERATING COST: The direct cost of any material, energy and labor necessary for the operation of the system and any indirect costs attributable to them.

OVERHEAD COST: The summation of overhead cost attributable to the program together with any unattributable fixed overheads.

OWNERSHIP COST: The sum of the O&S costs and disposal of the system.

PARAMETRIC ESTIMATING: An estimate made by using an expression relating cost to selected system parameters, performance requirements, or goals.

POST DESIGN SERVICES (PDS) COST: PDS cost applies to hardware and software and is comprised of the cost of the upkeep and amendments to technical documentation, defect investigations, the development and design of modifications arising out of defects, the production of modification kits, and where applicable, the cost of the supplier installing the modifications in the field. Also included under this heading are the costs of any CIP embarked upon.

PROCUREMENT COST: The total cost of providing a fully operational system and its supporting facilities in the required quantities locations, but not including RDT&E costs.

PRODUCTION COST: The total cost to the customer of buying the required numbers of the system. It must also include, when applicable, the cost of delivering the units from the contractor to the customer.

PRODUCTION INVESTMENT: The amount of investment necessary to enable the production of the system.

REGRESSION ANALYSIS: A statistical technique for expressing functional relationships between quantities that can be measured or observed, and quantities that are to be predicted on a probabilistic basis.

RELIABILITY: The ability of an item to perform a required function under stated conditions for a stated period of time.

REPLACEMENT COST: The cost of buying a substitute system to maintain a required continuous capability when the primary source is unavailable.

2.3 (Continued):

RISK: As used in cost-effectiveness analysis and operational research: the product of the consequence of an outcome and its probability of occurrence.

SENSITIVITY ANALYSIS: Repetition of an analysis with different quantitative values for cost or operational assumptions or estimates such as hit-kill probabilities, activity rates, or research and development (R&D) costs, to determine their effects for the purposes of comparison with the results of basic analysis. If a small change in assumption results in a proportionate or greater change in the results, then the results are said to be sensitive to that assumption or parameter.

SIMULATION: The construction of a working mathematical or physical model presenting similarity of properties or relationships with the natural or technological system under study.

SUPPORTABILITY: The degree to which system design characteristics and planned logistics resources, including manpower, meet system availability requirements.

SUPPORT COST: The sum of nonrecurring and recurring costs attributed to the ownership and operation of the system over its whole life.

NOTE: R&M have a strong influence on LCC; there exists a two-way relationship with acquisition cost and a subsequent effect on the support and unavailability costs.

SYSTEM: A composite of equipment, facilities, and services which make up an entity. The complete system includes the prime and all support related equipment, materials, facilities, and personnel required for obtaining, operating, and maintaining the system.

SYSTEMS ENGINEERING: The application of scientific and engineering knowledge to the planning, design, construction and evaluation of systems and components. It includes the overall consideration of possible methods for accomplishing a desired result, determination of technical specification, identification and solution of interfaces between parts of the system, development of coordinated test programs, assessment of data, ILS planning and supervision of design work.

TARGET: Used in a contract to define the customer's objective. It is sometimes used as the basis for an incentive arrangement, is normally more ambitious than a goal, but sometimes used interchangeably with "goal".

THEORETICAL STUDIES COST: The costs arising out of the execution of initial theoretical studies related to a system project.

TRADE-OFF (ANALYSIS): The determination of the optimum balance between system characteristics (cost, schedule, performance, and supportability).

2.3 (Continued):

UNAVAILABILITY COST: The sum, over the life of a system, of the cost incurred providing replacement facilities to maintain the specified requirement when the primary source is unavailable.

NOTE: This implies that the unavailability cost also includes the cost of unscheduled maintenance work arising if either reliability, maintainability or availability levels fail to meet the specification. In addition, R&M have a strong influence on LCC; there exists a two-way relationship with acquisition cost and a subsequent effect on the support and unavailability costs.

UNCERTAINTY: A situation is uncertain if there is no objective basis for assigning numerical probability weights to the different possible outcomes or there is no way to describe the possible outcomes.

UNSCHEDULED SUPPORT COSTS: The cost of unscheduled maintenance work arising because any or all of reliability, maintainability and availability fail to meet the specification.

WORK BREAKDOWN STRUCTURE (WBS): A product-oriented family tree composed of hardware, services, and data which result from the identification of acquisition tasks during the development and production of a system or equipment, and which completely describes the program or project. A WBS displays and defines the product to be developed or produced and relates elements of work to be done to each other and to the end product.

3. LCC:

This section defines LCC, discusses the major program phases in terms of acquisition and ownership costs, and defines the intermediate phases. The relationship between actual and predicted costs is discussed in connection with the decreasing opportunity of cost reduction as the program matures.

Major cost profiles for different programs are compared to illustrate pertinent economic variations, types of costs, and IAs that can ultimately influence the decision.

Various estimating techniques are introduced and their suitability during different program phases is discussed. An example of a CER is used to illustrate the relationship between certain influencing factors. Sensitivity and the need for consistency is discussed.

3.1 Description:

LCC is defined as the sum of all monies expended, attributed directly and indirectly to a defined system from its inception to its dissolution encompassing the acquisition, ownership, and disposal phases of a program. In addition, if the system being studied must maintain continuous capability of performing a specified task, then LCC must also include expenditures which arise because the primary provider of the capability is unavailable and a replacement is required. However, for most comparative purposes it is only necessary to identify those cost elements that are directly attributable to the system or subsystem, or that differ between the options being compared. In general, LCC issues need to be addressed initially during the conceptual studies phase when a specific program requirement has been established.

3.2 Program Phases:

The elements of LCC are related to the principal program phases depicted in Figure 1, and are broadly defined as follows:

a. Acquisition

(1) RDT&E
(2) Investment or procurement

b. Ownership

(1) O&S
(2) Disposal or phase out

3.2.1 Definitions (see glossary):

a. Acquisition

(1) RDT&E: The sum of all contractor and government funded costs required to bring a product's development from inception to production. They include engineering design, analysis, development, test, evaluation, and management.

(2) Investment: The sum of contractor and government in-house costs both nonrecurring and recurring, required to transform the results of R&D into a fully deployed operational system, including elements for production tooling and setup costs.

b. Ownership

(1) O&S: The sum of all costs, including contractor support, associated with the operation and maintenance of a system and support equipment.

(2) Disposal: The sum of all contractor and government in-house costs required to remove the system or equipment from the inventory, and which may be offset by some residual value.

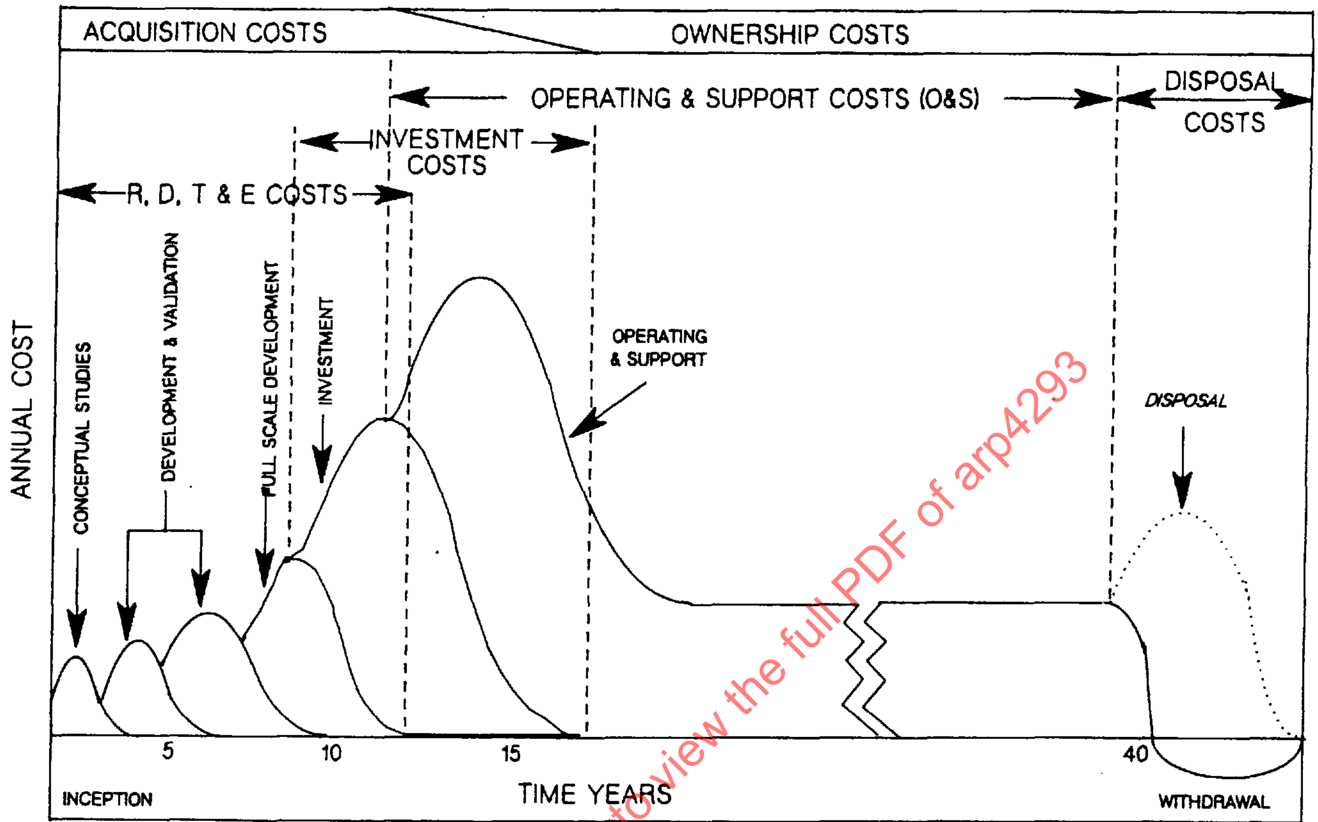

FIGURE 1 - Phases of the Life Cycle

3.3 Analysis:

LCC information includes both actual and predicted costs spread over many years. The timing and distribution of expenditure varies from program to program. The commitment and expenditure profiles of a typical program are shown in Figure 2. This illustrates the lag in the actual expenditure profile in comparison to the level of commitment or influence which is experienced during the phases of a program life cycle.

Note that as time elapses and decisions are put into practice, the scope for alternative approaches is progressively eroded. In most cases, such erosion takes place rapidly during the initial part of the development process. For example, Figure 2 shows that although around 15% of the LCC may have been spent, some 75% of the design decisions may be irrevocable and have the most impact on the O&S phases (Reference 1).

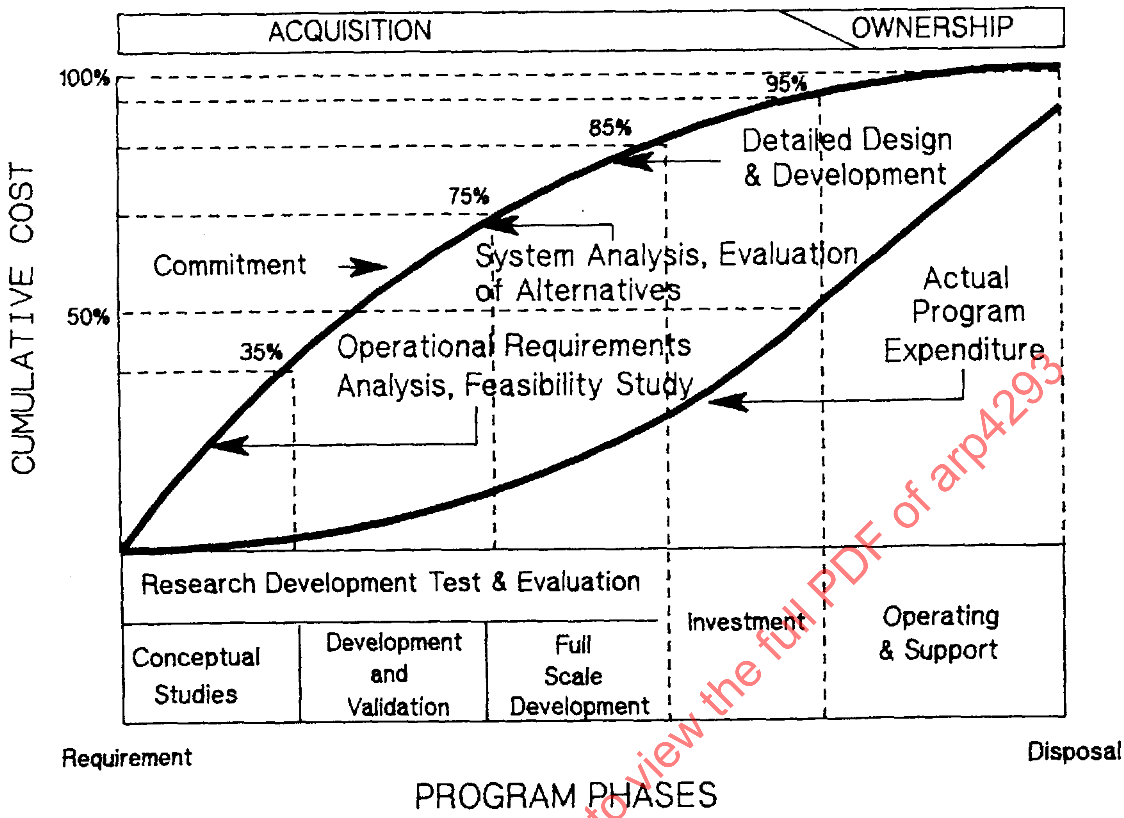

FIGURE 2 - Influence of Program Decision Stage on LCC

The significance of LCC reduction opportunities is reflected in Figure 3. Cost profiles for a typical program are illustrated schematically in Figure 4.

Alternative solutions may have comparative cost profiles which differ significantly in magnitude and time scale. These factors can have a major influence in the decision making process.

Funds for the different options are projected to be expended at different rates and time scales; therefore a common baseline or reference point is used when making financial judgements. The effects of inflation, interest rates, and exchange rates are some of the factors that must be considered. Failure to recognize these factors could have a significant influence on the final outcome and selection.

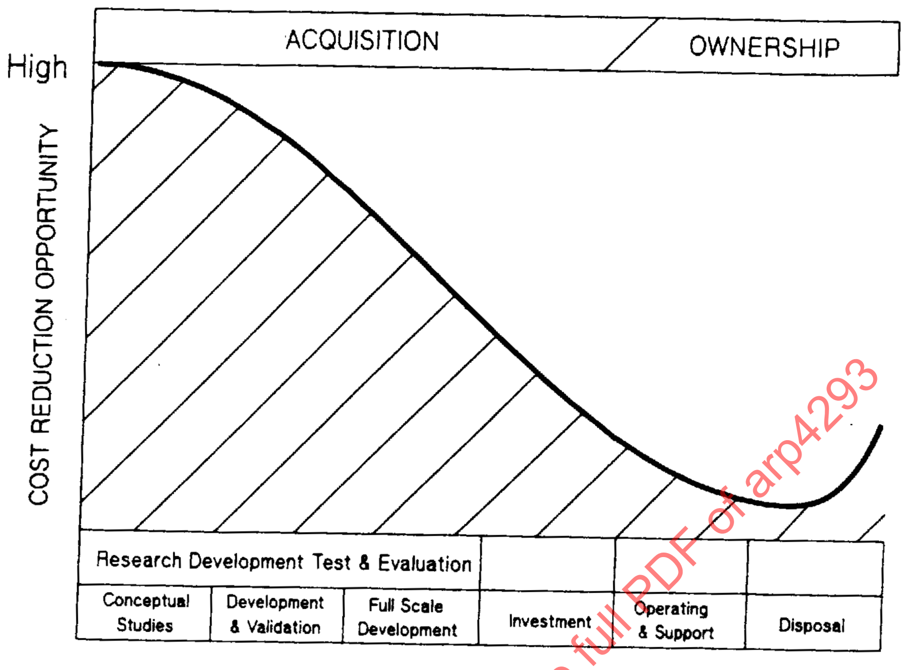

FIGURE 3 - LCC Reduction Opportunities

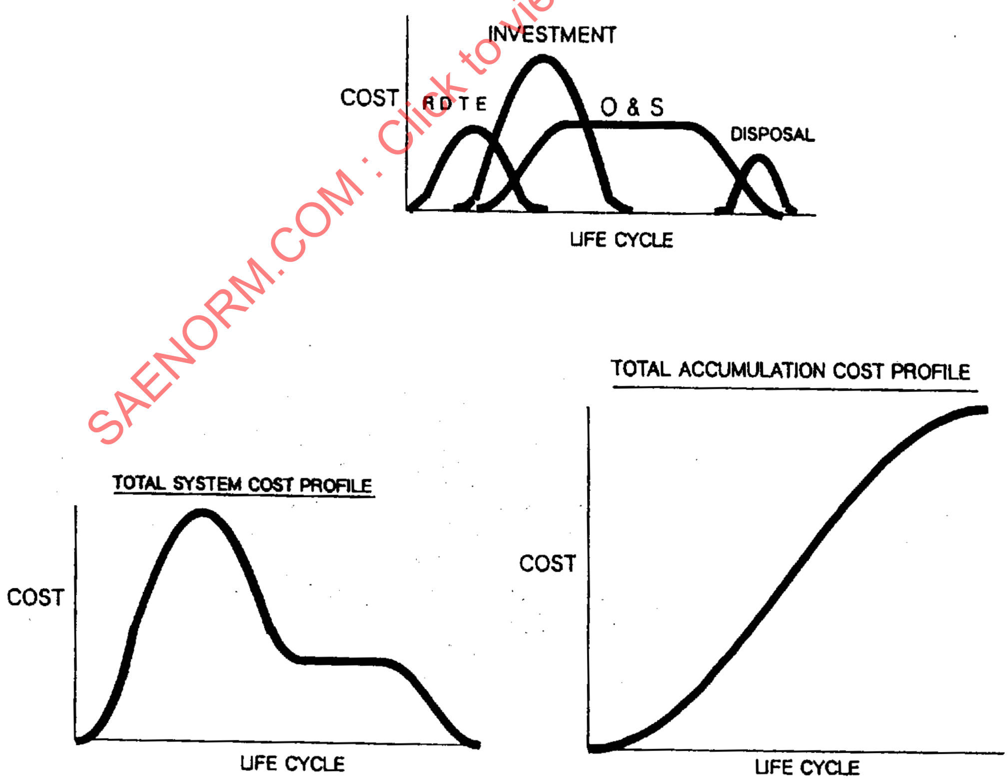

FIGURE 4 - Cost Profiles

3.4 Economic Variations:

The price the customer ultimately pays for equipment depends on how economic conditions vary during the course of the program. Hence, in order to forecast affordability against a given budget, the effects of the variations in rates of inflation and interest rates, and the effects of exchange rate fluctuations must be taken into account. Exchange rates are volatile and can introduce serious errors into cost estimates. Therefore, the use of a range of long-term forecasts of exchange rates is recommended for sensitivity assessment. Defense specific inflation is known to be higher than the general level of inflation summarized in the retail price index; an additional amount, such as 1.5%, is necessary to take this into account. This historical rise at a steeper rate than the price indices is termed the relative price effect (RPE) and along with the allowances for risk is treated separately in any program estimate. The cost of raising money is reflected in the discount rate which is taken into account through the use of discounted cash flow (DCF).

3.5 Investment Appraisals:

Investment appraisals using DCF techniques are in wide usage and provide an effective method in the decision making process. There are some constraints that need to be recognized when using this technique. Undiscounted cost profiles for alternative solutions to a requirement are illustrated in Figure 5 and indicate some of the variations that can occur.

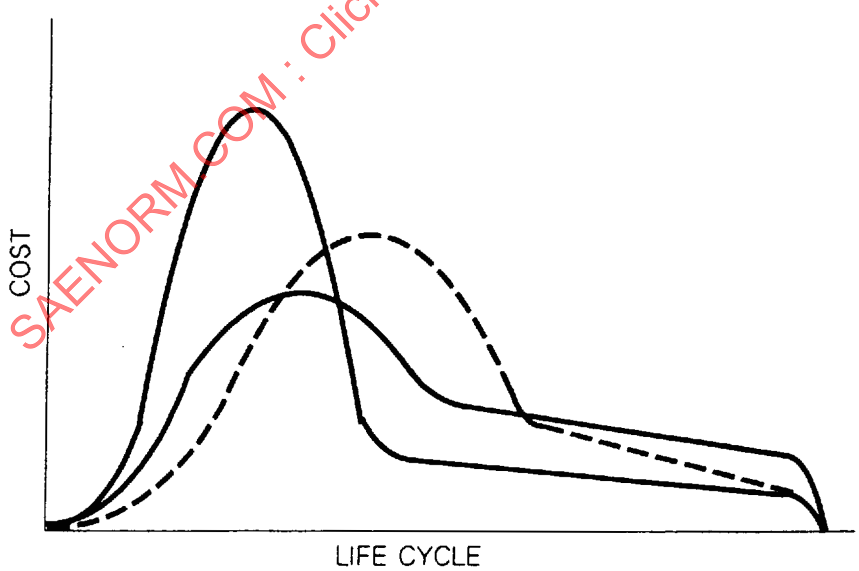

FIGURE 5 - Undiscounted Cost Profiles for Alternative Solutions

3.5 (Continued):

One option offers significant cost benefits in the O&S phase of the program, but at the expense of a higher acquisition cost. This may be a necessary expenditure in order to capitalise on a technological improvement. Although these situations are rarely experienced in real terms, they represent possible issues to be faced. In practice, more complex problems and issues are prevalent; complicated by uncertainty, risk and discounting.

3.6 Application of Techniques to Program Phases:

Dividing lines between phases are not rigid and may overlap in time scale. Figure 1 illustrates a typical program with overlapping phases having an overall duration of 40 years.

3.6.1 Cost Factors: At the inception of any program, costs can only be predicted, while at the disposal stage, costs are sunk. Between these two extremes, cost is a combination of sunk, committed, planned, and speculative/projected costs as illustrated in Figure 6.

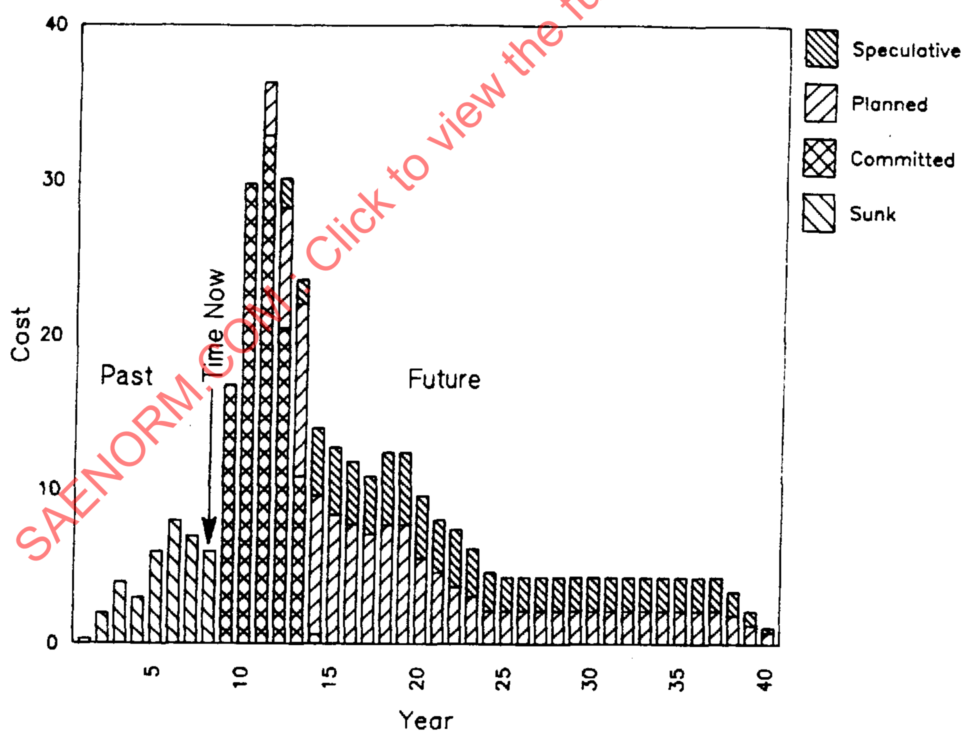

FIGURE 6 - Typical LCC Degree of Commitment

3.6.1 (Continued):

Decisions can only affect the future. Costs already incurred (sunk) are therefore irrelevant to decision making. They have no value beyond that which emerges naturally from estimates of future costs. Many different factors affect the end costs; the degree of accuracy for prediction of these costs improves with the maturity of the program. However, this improvement (reference 5.3) is countered by the fact that influence on the final cost is considerably reduced, particularly at the start of the production phase.

3.6.2 Expenditure Profile: The cumulative expenditure profile in Figure 8 is based on the cost profile in Figure 7 and the commitment profile in Figure 6. This expenditure profile puts into perspective the significant level of expenditure which is associated with the cost of ownership during the O&S phase. Useful life for most aircraft systems may exceed 20 years.

3.6.3 Estimating Techniques: Much LCC analysis takes place during the early stages in a program life cycle, when there is a shortage of reliable information. Estimating techniques applicable at this stage are analogies, parametric, or statistical analyses. It is neither practical nor desirable to attempt to define an exact relationship between program phases and various LCC techniques. However, a generalized relationship is illustrated in Figure 9, which indicates the type of technique most suited for each program phase and level of expenditure (Reference 3). The techniques become more extensive as more definitive information becomes available.

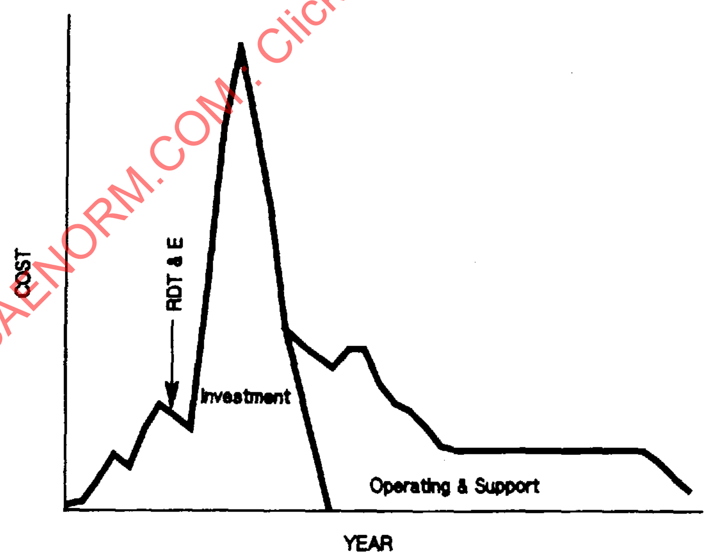

FIGURE 7 - Expenditure Profile

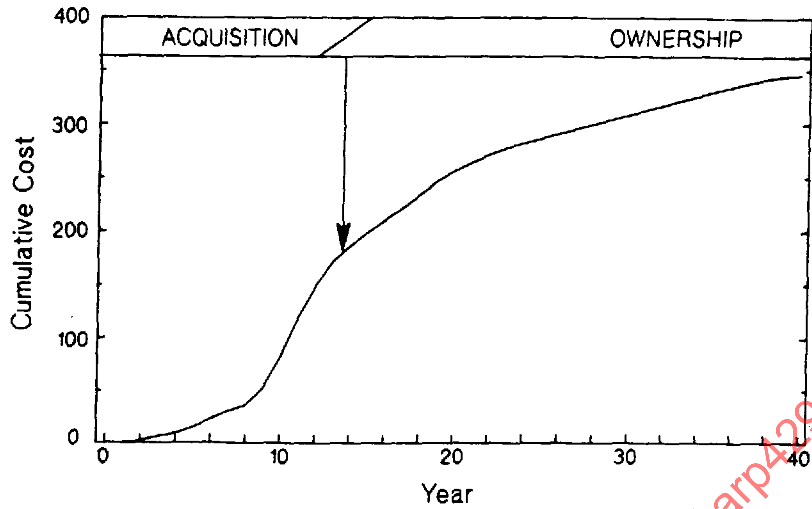

FIGURE 8 - Typical Cumulative LCC Expenditure Profile

PROGRAM PHASE	TYPICAL SUNK COST	TYPE OF SUPPORT PROBLEM	LCC MODEL TYPE
CONCEPTUAL STUDIES	1%	Project Alternative Analysis	Parametric
DEVELOPMENT & VALIDATION	10%		
FULL SCALE DEVELOPMENT		System Alternative Analysis	Parametric/Simulation
-Definition	15%	Vendor Evaluation/System Simulation	General 'Top-Down' Accounting/ Monte Carlo Simulation
-Design Phase	20%	Design Alternative (Trade Off)	General 'Bottom-Up' Accounting/ Complemented by:- Sensitivity Analysis Trade Off Cost Estimating/Accounting Monte Carlo Simulation
-Test & Evaluation	20-25%	Maintenance Concept/ Test Interval Optimization Discard/Repair Repair Level Analysis	Trade Off Cost Estimating/Accounting Monte Carlo Simulation
INVESTMENT		Logistic Resource Optimization	Queueing Model/Accounting
- Start Up	25%	Spares Optimization	Dynamic Programming/Accounting
- First Production	25-30%		Marginal Cost Effectiveness
- Service Entry	30%		Accounting
- Full Scale	30-40%	Budget Estimation	Accounting Monte Carlo Simulation
DEPLOYMENT/OPERATIONS	40-95%	Modification Evaluation	Cost Estimating/Accounting
PHASE OUT	95-100%	New or Modified Old Project	Cost Estimating/Accounting/ Cost Estimating Relationship Monte Carlo Simulation

FIGURE 9 - Phased LCC Model Relationships

3.6.4 Cost Estimating Relationships (CERs): In the early stages of a program's evolution, parametric estimates are typically used. These estimates rely on a series of CERs to a given set of parameters. The grouping together of a number of CERs and the subsequent algorithms can form a LCC model for a particular phase of the life cycle. For example, Figure 10 illustrates a CER where the development cost for an aircraft is related to its designed dive speed and empty weight.

Models are calibrated on the basis of previous experience and performance and should be recalibrated regularly. Design criteria inputs such as mass, speed, density, durability, and MTBF can vary by task (Reference 4). The relationship of these historical parameters with cost of a specific element from a previous product can be compared. The relationships are normally derived by regression analysis of data gained from past programs. The CER can then be used to predict future cost and logistic data with reference to future parameters of the product.

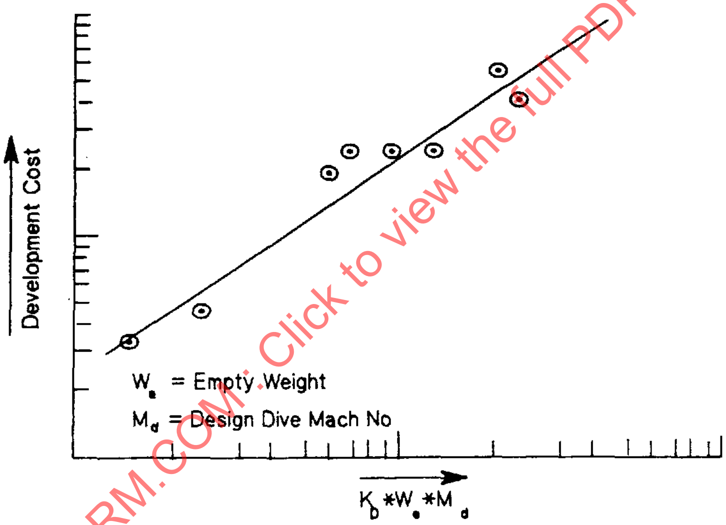

FIGURE 10 - Military Airframe Development Cost

3.7 Consistency:

LCC analyses should be accompanied by sufficient explanation of the underlying assumptions related to its cost elements for understandability and traceability. Consistency is, therefore, important both in the definition of terms and in the costing and accounting conventions used. Standardization and commonality in nomenclature, definitions, and approach are keys to projecting consistency in information transfer.

It is also important that the accuracy of the cost elements is defined. The relative accuracy of LCC estimates is important in determining their value, validity, and the extent to which they can be used unadjusted in procurement decisions. Point estimates should be accompanied by a sensitivity analysis of the major cost drivers.

3.7 (Continued):

A significant cost driver of program risk is "time of arrival" which predicts the arrival of a given level of technology. Experience suggests that program risk is proportional to the difference between scheduled and expected qualification dates. A confidence range of estimated costs can also be used for assessing the financial and technical risks involved, particularly during the acquisition phase. Most organizations develop their own LCC models using CERs that relate to their own statistical data base and reflect their own performance.

The estimation of O&S costs for a program at the early conceptual stage requires the application of analytical techniques. Estimating procedures first use statistical analysis of historical data then use prediction of R&M characteristics based upon experience gained from the development program.

As the program advances and operational data is accumulated, simulation of the logistic elements becomes feasible. Simulation provides the ability to investigate the complex interplay between random events and those with time-related variations, and more explicitly evaluate uncertainty.

4. LCC TECHNIQUES:

This section discusses LCC analysis, the need to recognize risk and uncertainty; to relate current and past estimates and the identification of major cost drivers. Accounting and predictive estimating methods, including "top-down" and "bottom-up" approaches are introduced. The importance of selecting the best technique or combination of techniques, appropriate to the particular program phase is discussed.

An integrated structure of interactive models, deployed to support trade-off studies and to attain the most cost-effective solution is reviewed. Predictive and accounting techniques are further defined and developed. A typical cost structure is introduced and an integrated approach is advocated. This illustrates the combination of acquisition and ownership cost models linked to both operational requirements and supporting data bases. They assist in the formulation of meaningful LCCs.

4.1 Objectives:

The objective of LCC analysis is to assist in a meaningful evaluation of any new program, option, or trade-off. The estimate should be as accurate as possible given the stage at which the assessment is being undertaken. Risks and uncertainties should be recognized and defined, if possible. The estimate should be consistent. Succeeding estimates should be related to previous estimates while accounting for variations. The estimate also should be appropriate. It is not necessary to apply the full rigors of the LCC discipline to arrive at a meaningful result. It is not essential to use absolute data. Relatively less detailed data may be used when circumstances dictate.

4.1 (Continued):

Processing the data requires a set of well defined rules involving factual accounting and expert estimating. However, there is a limitation to the degree of accuracy that can be achieved. Risks and sensitivity issues need to be assessed and evaluated. In addition, LCC estimates can be limited to those few elements of LCC known to account for most of the total, i.e., selection of those elements from a Pareto (80:20) analysis.

4.1.1 Estimating Methods: Methods of cost estimating are classified according to where they exist between two pairs of extremes (see Figure 9). They come between pure "accounting" and pure "predictive" types and the extent to which they proceed in a "top-down" rather than a "bottom-up" fashion.

4.1.2 Program Costs: LCC represents the totality of "cradle to grave" program costs, depicted by a complex set of data bases, modelling and predictive techniques and accounting rules. The selection of the most appropriate techniques and the way in which they are combined depend to a large degree on the purpose of the study and the stage the program has reached. Simple parametric models are used at the beginning of a program with more sophisticated and comprehensive models being applied as the program develops.

It is more common for cost performance to be monitored against projected cost profiles with the ability to investigate and institute improvement programs. However, this is dependent upon the creation and sustained maintenance of accurate and integrated data bases.

4.1.3 Procurement Decisions: Most major procurement decisions are concerned with attempts to estimate and balance cost, logistic and effectiveness considerations. Costing techniques cannot be used in isolation without due regard to other influencing factors. The interrelationships between other models forming this integrated framework are illustrated in Figure 11.

The fundamental requirement in any analysis is cost effectiveness; (i.e., the system being evaluated shall exhibit the prescribed performances at the established level, with continuity throughout the life cycle and with the minimum LCC). This perspective, which is extensively being adopted in the present environment of budget restrictions for system acquisitions, has dramatically changed the current procurement process.

However, the approximate nature of any model dictates caution in its application. Considerable residual uncertainty remains until the limitations of the approximations are clearly understood and taken into account in any decision making process.

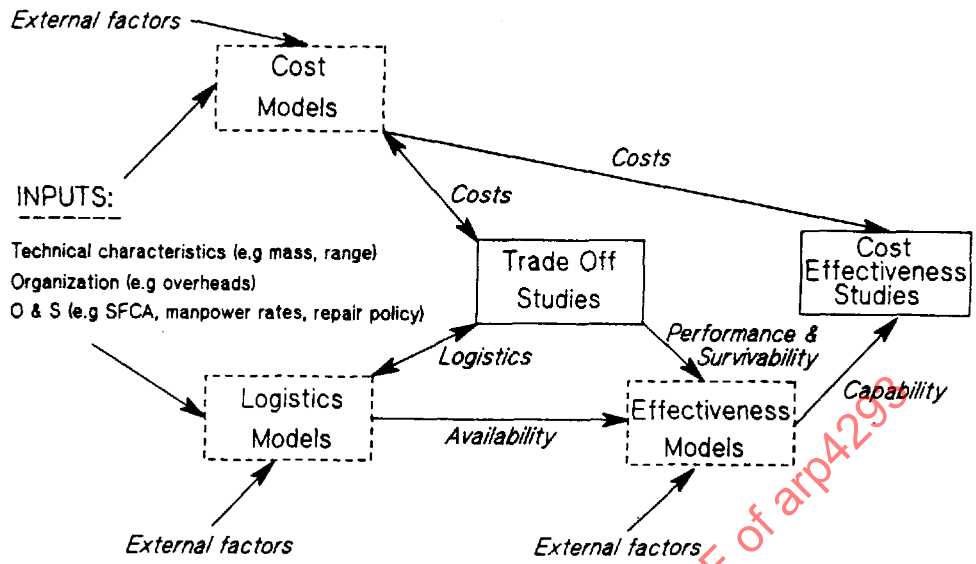

FIGURE 11 - Integrated Structure

4.2 Cost Estimating Techniques:

Important differences in the construction of formal mathematical and accounting models need to be understood to evaluate modelling concepts. Two distinct types of techniques are used to derive costing data, those that are "accounting" in nature and those that "predict" the value of cost elements.

4.2.1 Predictive Techniques: The earlier the stage of the program, the greater the requirement for predictive techniques. Predictive models are used to forecast the value of various cost elements required as input to the accounting model and make use of a wide variety of techniques. Both classes of models may be combined into a single one, though it is useful to separate the distinctive functions. The predictive techniques can be further described as being either stochastic, parametric, or analogous.

Stochastic models take into account the random nature of events and rely on specialized statistical techniques. These models are usually restricted to simulating certain elements of logistics, although they have been applied to the acquisition phase.

Parametric techniques are based on statistical analysis of historic data bases and usually result in a cost estimating or cost factor relationship. The scale of application range from individual components or subassemblies to a complete system. Again the appropriate level of detail is driven by the stage of advancement of the program.

Analogous techniques draw on relationships between current and similar previous programs. Expert judgement is used to make adjustments to the previous program data to reflect characteristics of the program under consideration.

4.2.2 Accounting Techniques: Accounting models assemble and distribute costs determined by a defined breakdown structure to describe the total cost of the system in operation. This is an extensive exercise if all costs are captured.

Difficulties arise with identifying the "overhead" element of the O&S costs. This arises because of the complexity of identifying activities that are not directly attributed to specific functions of a system but which, nonetheless, arise from ownership.

4.2.3 Cost Structure: The list of cost elements allocated within an LCC statement is called a "cost element breakdown structure". This structure ensures accurate communication of LCC information between the customer and equipment suppliers, and when used within joint ventures. Flexibility is required so that the structure may be clearly tailored to suit different study types and data availability. Most of the information will be generated by the prime contractor and suppliers. However, there are some aspects, particularly in the O&S area, which are dependent upon input data being supplied by the customer. This is required in order to arrive at a meaningful overall LCC.

The LCC element structure is not the same as a work breakdown structure (WBS). Both structures fulfill different program requirements even though some elements may be common. The WBS is composed of a detailed breakdown of hardware, services, and data which identifies all major tasks and supporting work packages. These must be fulfilled in order to achieve a given program of work. The WBS provides a list of tasks to be monitored which comprise a given program and is linked to program milestones. The LCC element structure presents a breakdown of costs incurred over the major phases of the complete life cycle of a program. It is important that this distinction is clearly understood. Aspects of an LCC analysis may need to be constructed from data arising from a WBS task and they must be used in the correct context.

ARP4294 provides a detailed scheme for a cost element breakdown structure specific to propulsion systems (Reference 5). This document provides a typical "global" LCC element breakdown structure for an overall system which expands the acquisition and ownership phases as illustrated in Figure 12 with details in Appendix A.

The level of element breakdown detail should be consistent with the decisions to be taken and its influence on the final cost. The distinction between driver and driven costs is also an important aspect to identify, particularly when conducting sensitivity analyses. Costs should be normalized to a common baseline using financial indices.

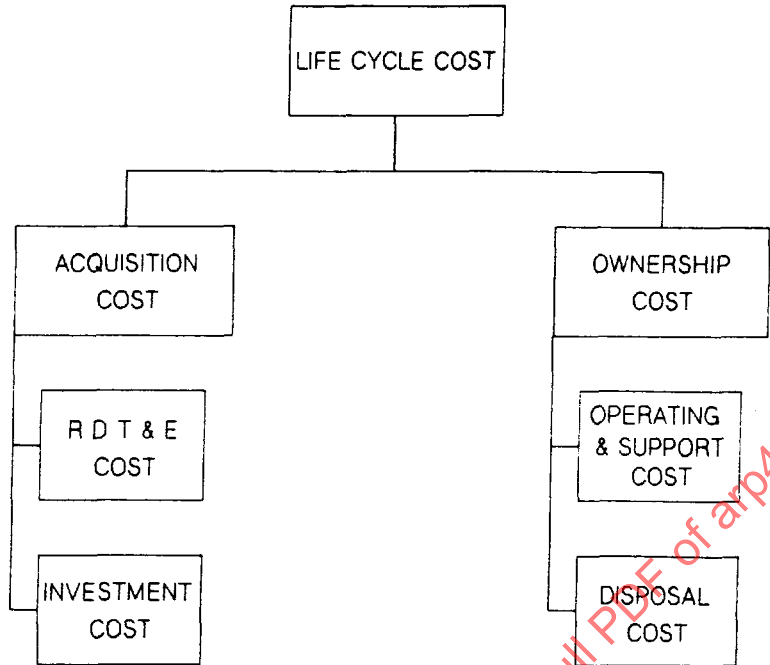

FIGURE 12 - LCC Structure

4.3 Modelling Aspects:

LCC models translate input data into an output format based upon cost elements, parameters, and interrelationships between these elements and parameters. Each model needs to be tailored to the specific needs of a program.

4.3.1 Characteristics: Whether accounting, predicting, or a combination of both, a model may broadly be characterized as either "bottom-up" or "top-down".

"Bottom-up" models collect the cost of the whole by adding up the detail. This approach mimics the way costs arise in practice and can provide great detail and precision but is prone to significant underestimation through inadvertent omission, especially of "overhead elements" and integration costs.

"Top-down" models estimate a global cost and distribute it to the detail required. This method forecasts directly the costs of major sub-systems (e.g., engine, airframe or avionics), or even a complete aircraft system.

These estimates are based on statistical analyses of the costs of existing systems using a few salient characteristics as explanatory variables. For example, Figure 13 indicates, for a range of engines, support costs based on their UPC and mission sortie length (SL).

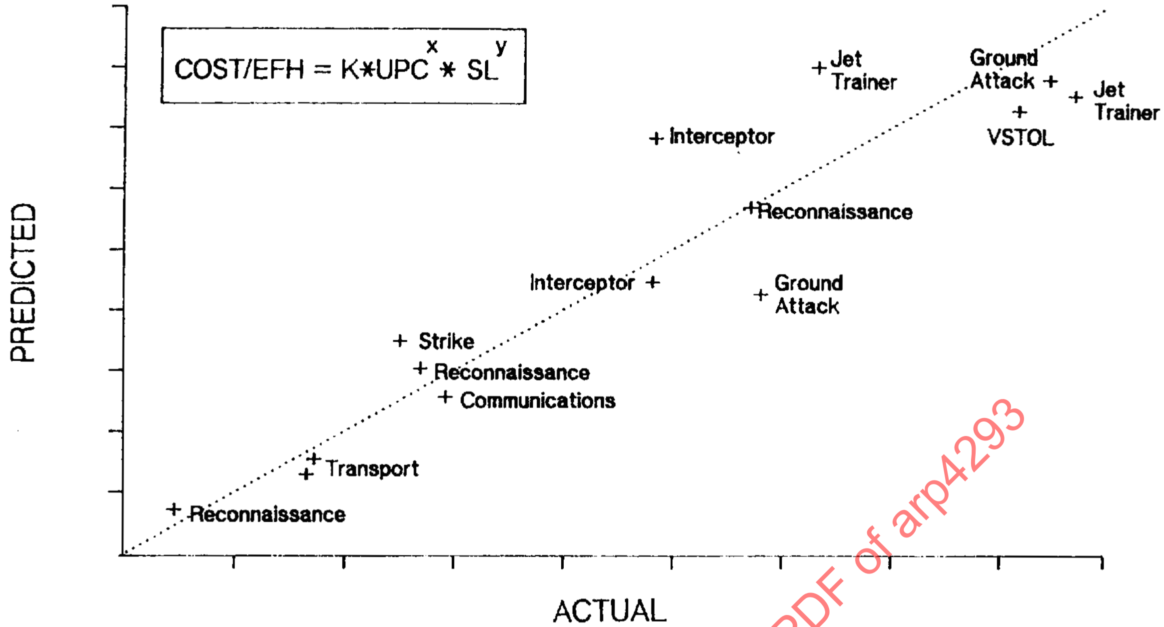

FIGURE 13 - Engine Support Cost per EFH

4.3.1 (Continued):

Successful prediction depends upon constant correlations between explanatory variables and their surrogates. This is a common reason for objection to this forecasting method. However, if explanatory variables are well chosen then there is more continuity with the past than is supposed even in cases of "revolutionary" technical change. "Top-down" is the more useful technique for estimating the cost of future systems which often lack the detail demanded of a "bottom-up" approach. Detail can be obtained from a "top-down" approach only by a process of disaggregation. However, there are practical limits on how far this process can be carried.

4.3.2 Accounting: Accounting models involve the creation of a breakdown with clear and unambiguous definitions utilizing simple arithmetic. This class of model is fairly easily described and once established is likely to remain stable.

4.3.3 Predicting: Predictive techniques utilize a number of methodologies to make predictions from whatever data exists. These techniques apply expert engineering judgement, statistical analysis, and formal algorithms. Successful application of predictive techniques requires constant revision of the data base to take into account new information as it becomes available.

4.3.4 Precision: Precision of parameters and the random nature of the outcome of events are an ever present problem in making cost estimates. They may be treated in a deterministic manner where probability distributions and their characteristics are processed exactly or treated stochastically using simulation. Simulation techniques are quite common in logistics and effectiveness models. However, their use in cost models, relative to estimating uncertainties and program risk, have not yet been fully exploited.

4.3.5 Integration: The cost estimation approach should integrate all relevant issues. One solution is illustrated conceptually in Figure 14. It considers a fully integrated model that takes into account all influences in deriving LCC. It is essential that when any study is undertaken that the interface effects are not ignored. When an engine manufacturer performs system LCC studies, the effects of the engine on airframe size and, therefore, costs should be considered.

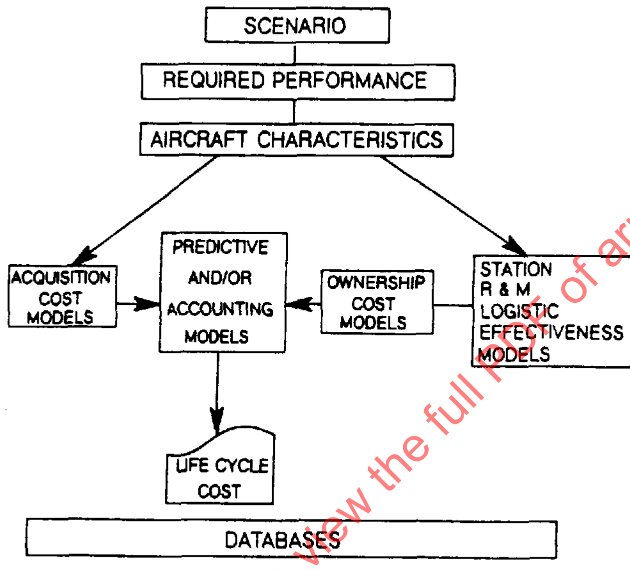

FIGURE 14 - Overall Structure

This LCC modelling structure integrates predictive models, used in estimating acquisition costs, with central accounting models. These are supported by models used to predict direct and indirect support costs. This structure illustrates that procurement and in-service activities are distinctly different and involve the interplay of different resources. This also illustrates the practice of isolating acquisition cost estimates for budgetary purposes. The direct and indirect cost models are merged with the logistic models. These in turn provide the links with the effectiveness models, bridging the gap between measures of costs and measures of performance. The foundation of these models is a general relational data base, and driving them are the specific aircraft or system characteristics (Reference 6). The latter reflect the performance requirements and the scenario details for any particular evaluation.

5. LCC APPLICATION GUIDELINES:

This section discusses the value of LCC in deciding among alternative solutions to meet an operational requirement and the benefits arising when adopted during the various program phases. The effects and attribution of cost errors is discussed along with mechanisms which minimize their effects. Examples of risk and uncertainty are given to illustrate the problems which arise in failing to recognize them.

5. (Continued):

The adoption of IAs, including the use of discounting, is further discussed. The influence that DCF has on "up-front" investment is highlighted. Variations in the ratio of acquisition to cost of ownership is considered. The need to reduce O&S costs through the introduction of "spend to save measures" is addressed.

Future direction and trends are briefly reviewed. The integrated approach to designing for support is a key area for further improvements in R&M. Improvements in the services support structure is identified, in particular the need to obtain accurate data on actual performance.

5.1 Guidelines:

In assessing the operational need for a new aircraft system, LCC is used to assist in deciding between alternative system level solutions. These are aimed at countering the perceived threat and achieving the mission requirements. Once a system has been identified, LCC techniques are used to evaluate alternative design options until a final cost-effective selection is made. Predictions of cost made during development can be continually monitored. Comparisons can be made throughout the program phases as an aid to program management. Investment in production and support facilities are also evaluated. Sensitivity studies are used to assess the effect of support policy changes.

5.1.1 Discipline: LCC provides a discipline which establishes a cost conscious attitude at the commencement of a program. This improves decisions and increases confidence in budgeting of funds, cash flow, and allocation of resources. LCC, therefore, has a positive role in evaluating alternative designs, maintenance concepts and procurement routes at an early phase. Figure 15 indicates the benefits arising from the application of LCC during the various program phases.

As the program proceeds, and real data becomes available, it is important that earlier predictions are checked, validated, amended, and resultant changes reassessed.

PROGRAM PHASE	MANUFACTURER APPLICATION	USER APPLICATION
Conceptual Studies	LCC Modelling on the basis of typical use of the product, or the user's specification. Rough analysis of LCC for comparisons of technologies and design concepts.	Establishing the LCC model and the cost driving parameters based on intended use. Defining LCC requirements and the manufacturer's responsibilities.
Development & Validation	Comparisons between alternative design solutions. Trade-offs. Identification of appropriate corrective actions in order to reduce the LCC.	Quotation evaluations by the LCC model and requests for complementary information. Choice of contractor (early in this phase).
Full Scale Development	ILS assessments Refine LCC estimates	Verification of ILS assessments and LCC estimates
Operating & Support	Verification of parameters assessable from product use and Maintenance reporting.	

FIGURE 15 - Applications of Life Cycle Costing

5.2 Cost Realism:

Cost errors in general, can be attributed to two principal sources. The first are those due to inaccuracies in the basic estimating techniques linked to the basic costing assumptions. Secondly, errors are due to changes of design or policy. The effect of the first type of error can be minimized by:

a. A "robust" model, which is updated or re-calibrated using feedback from program actuals.
b. The provision of clear tracks for derivation of models for auditing.
c. The use of relevant historical data to its fullest extent, particularly during the development phase.

There will always be evolution in the costing assumptions used during the early stages of any new program. There is a need to continually check estimates for data errors that can arise from so-called reliable sources. The second type of error cannot be eliminated, but its effects can be anticipated by sensitivity analyses. Some opinions advocate that data more than two years old are out of date due to the evolutionary nature of the designs under consideration. However, advancement of technology is met by a comparable increase in usage of the new capability; therefore, predictions using historical data are still relevant.

5.3 Risks and Uncertainty:

Any program will have risks that may ultimately impact LCC. From the earliest stage, feasibility of the program has to be assessed and associated levels of risk attributed to elements of the program. Throughout the acquisition phase, risks will arise with varying impact on the achievement of successful introduction into service. Risks are not all technical, such as changes in threat which cannot be anticipated. Also, finance could have a risk associated with it and could be a limiting factor on the ability to reduce a technical risk problem. Each program will be different, possibly involving risks with potentially catastrophic consequences. Even when individual risks have been identified and allowance made, their combined effects may not be obvious.

Technical risks may be such that the required performance cannot be achieved using the level or type of technology proposed. However, a more common situation is that the required performance can only be achieved by spending more time and money than was originally planned, with consequential changes to the costs of other program elements. The pressure to adhere as closely as possible to planned in-service dates for military or economic reasons can force premature transition to production. Extensive and expensive remedial programs, lasting well into the service life may be necessary. In addition fleet effectiveness may be compromised.

5.3.1 Risk Assessment: Inadequate risk assessment at all phases of a program, or failure to act in accordance with that assessment, results in an increase in the time and money required for the program. Since the defense budget is limited, the effect of time and cost overruns is not confined to the program of immediate concern but places other possible programs at risk. Thus it can start a chain of events which significantly reduces overall military capability. For this reason, it is important to express risks in terms of the financial provision required. Examples of recent cost overruns are illustrated in Figure 16.

Procedures for assessing risk should not be confined to the initial procurement stages of programs. Risk assessments should be repeated at intervals during the program, starting from the position currently achieved.

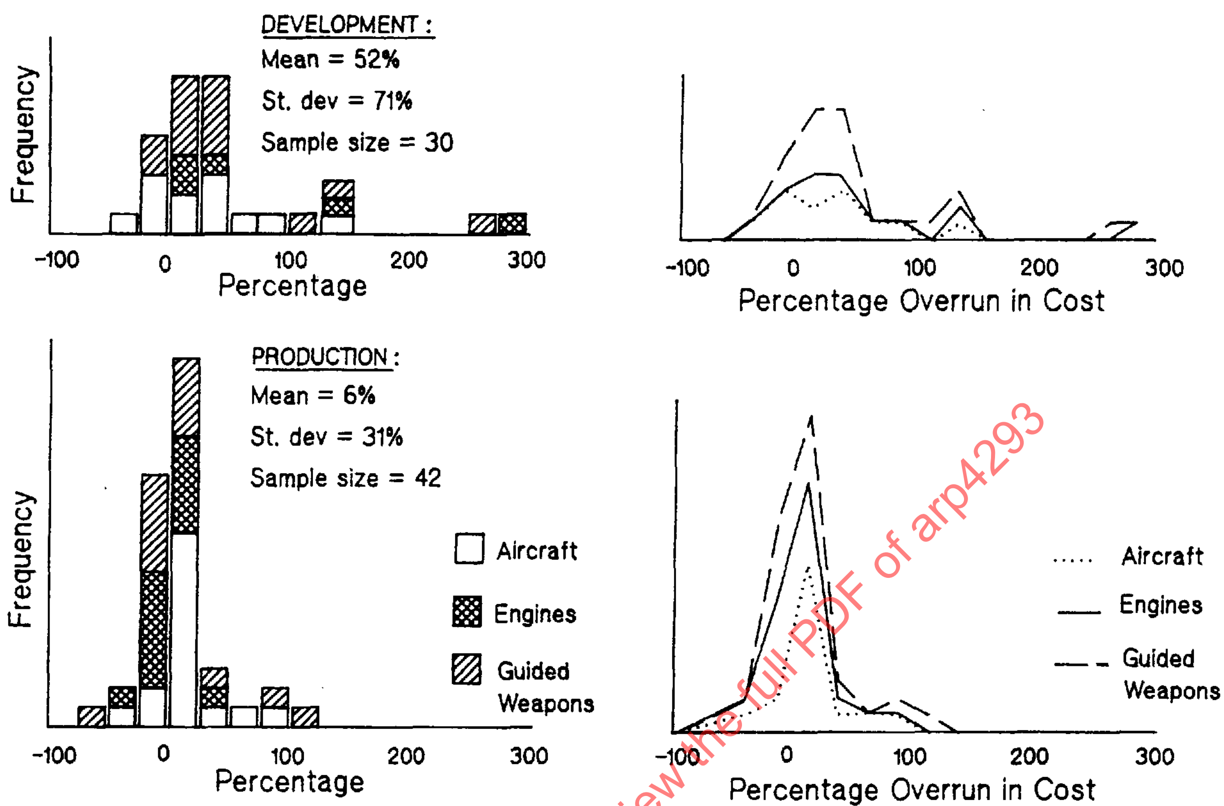

FIGURE 16 - Escalation in Program Cost

5.3.2 Dimensions: The risk associated with a program has three dimensions:

a. Time to completion
b. Cost to completion
c. Performance (including operating costs, reliability, availability, maintainability and operating characteristics)

These are all closely related so that pressure on one can dramatically influence others (Reference 7). Potential trade-offs need to be recognized and a balanced position taken at the earliest design and procurement stages. Circumstances will change as a program progresses and mechanisms for adjustment need to be developed. Factors that need to be considered include program cancellation, refunding, technical changes, resource availability, schedule conflicts, obsolescence, immature specification, exchange rates, and even natural disasters. Schedule constraints imposed on, or accepted by, the manufacturer to satisfy real or perceived customer demand or need, may result in nonoptimal configurations or inadequately developed designs.

5.3.3 Techniques: The residual uncertainty can be analyzed by means of a variety of established risk assessment techniques including, but not limited to, statistical analysis of historical data, structured application of expert judgement, and simulation of causal mechanisms.

5.3.4 Probability: Cumulative probability curves, as illustrated in Figure 17, are a useful tool for presentation of risk and uncertainty.

These curves indicate that a rapid improvement in accuracy is experienced after development has begun. The uncertainties that exist at the conceptual phase are really quite large. There is also a bias in the estimating process with a tendency to underestimate. For development, underestimates could be of the order of 50%. If these characteristics are overlaid on a plot of commitment versus expenditure, the full extent of the problem is exposed (Figure 18).

Uncertainty associated with high risk programs can be large and, therefore, unsuitable for budgetary planning purposes. However, early estimates are useful for comparing alternative options, in that they offer the possibility of adjusting the objective in order to fit the budget.

5.3.5 Impact: Not only is uncertainty large at the beginning of the development process, but this is when the effects of decisions have the greatest impact downstream (reference 5.3). For example, Figures 2 and 18 indicate that prior to entering full development, less than 15% of the LCC has been spent; however, 75% has been committed or influenced with a wide margin of uncertainty remaining. This level of influence could be as high as 90%.

Stochastic network techniques link the estimates of time, cost, and resources associated with each program activity with the inclusion of decision modes which represent the probability of a particular effect being successful and the consequences of being unsuccessful. This is illustrated in Figure 19 which shows the range of a number of simulations giving a maximum and minimum cost of a program.

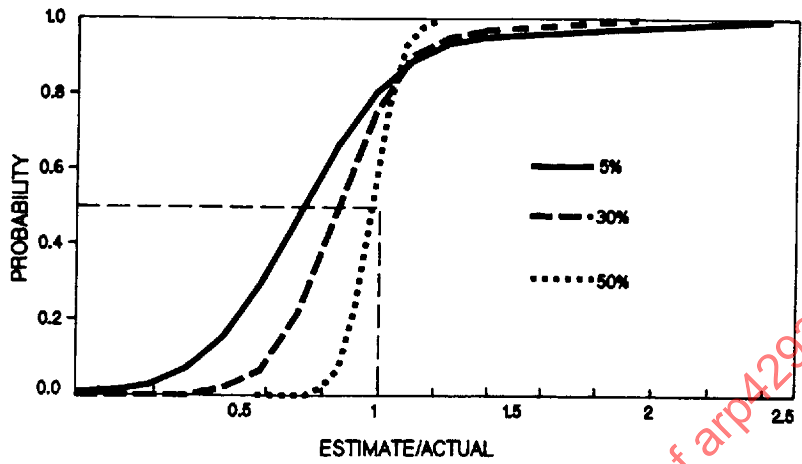

FIGURE 17 - Evolution of Estimates/Percentage of Project Completion

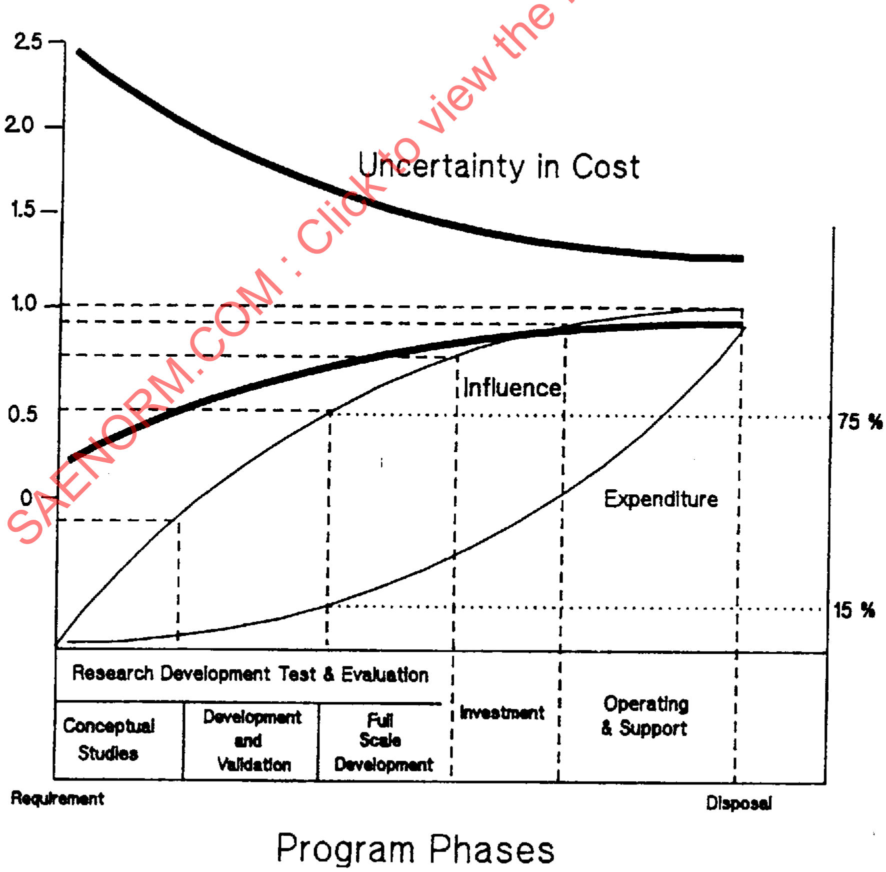

FIGURE 18 - Uncertainty in Cost

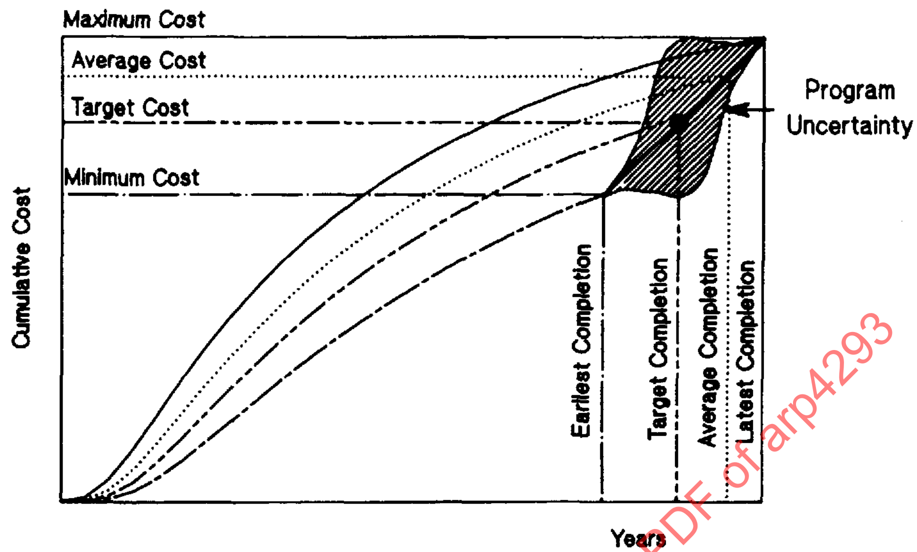

FIGURE 19 - Cost Performance

5.3.6 Simulation: Another technique used in risk analysis is to construct a simulation model of a portfolio of programs, which examines the effects of uncertainty in a stochastic fashion. This analysis is based on a data base from past programs which is updated as the programs mature. A typical situation is that total costs go up as time elapses, and programs slip, resulting in less expenditure in the early years, but more significantly, less funds available (headroom) for new programs in later years, as illustrated in Figure 20.

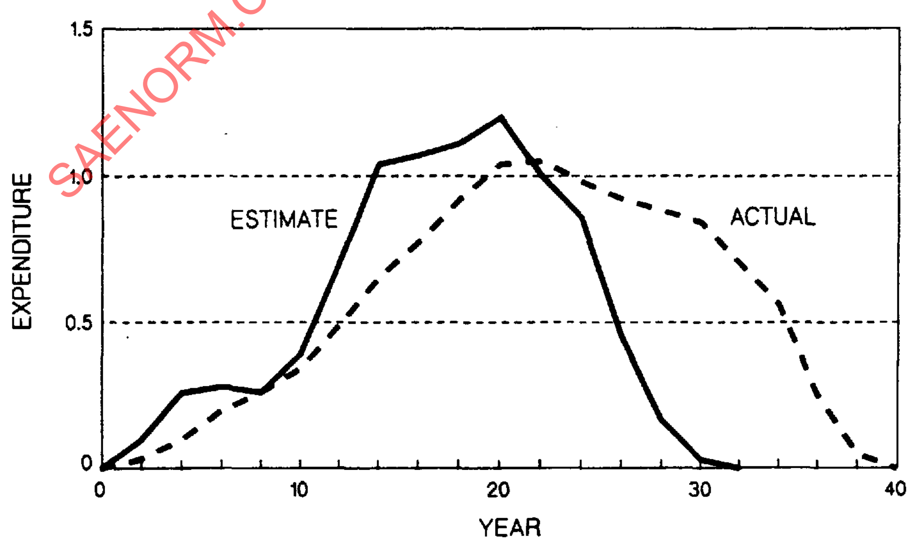

FIGURE 20 - Cost Estimate Evolution

5.3.7 Intrinsic Risks: Precise and detailed accounting for risk is inherently impossible. Development work is necessarily a venture into the unknown and must give rise to numerous interactive possibilities of failure or of encountering the unexpected. The establishment of a list of "all possible modes of failure" should be viewed with caution, since the most potent source of risk is the emergence of failure modes not defined at the start of the program. Uncertainty and imprecision are inherent in risk. Contingency allowances are, therefore, intrinsically incapable of detailed distribution within an LCC. An overall unallocated allowance may need to be established and held in reserve.

5.3.8 Alternative Strategies: Regardless of the method used to derive meaningful cost profiles for alternative programs, the resulting assessments produce data as shown in Figure 21. Comparisons can be made only if the scope of the risks and uncertainty is reflected in the analysis. The preference for any system is dependent upon a realistic assessment of the operational phase. Systems with the lowest acquisition costs do not necessarily infer that the condition pertains throughout the life cycle. Sensitivity analyses will considerably influence the final selection of the program offering the most effective solution. This is especially true when the known full term duration of the program occurs in the crucial overlapping area.

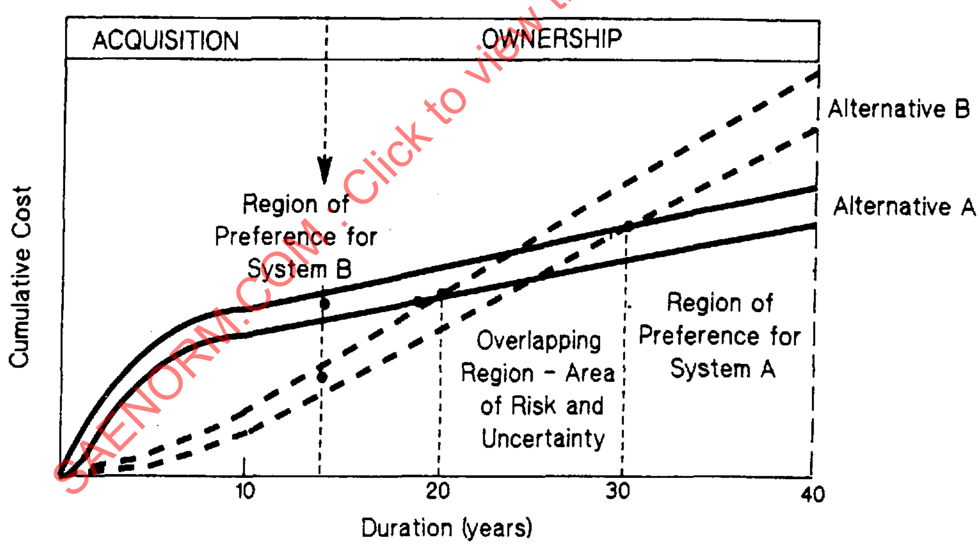

FIGURE 21 - Evaluation of Alternatives

5.4 Investment Decisions:

In recent years, greater emphasis has been placed on improving reliability, availability, maintainability, and other parameters that directly influence the O&S costs of an aircraft system. If costing techniques are being considered, which reduce the level of importance of O&S costs, then caution is advised when assessing competing design options.

5.4 (Continued):

Investment appraisals are used extensively and effectively in the private sector. They are increasingly being applied to public sector decision making in order to assist in the selection among a number of investment strategies. There are some constraints in the general adoption of this technique to the public sector. For instance, the use of discounting, for investment decisions made by government defense organizations, cannot be directly related to a monetary return. It is perfectly valid for commercial organizations to make investment appraisals. They can borrow or invest against immediate or future needs. Use of discounting is even more debatable in the context of a defense budget in which decisions are made for programs facing 20 years of financial uncertainty.

5.4.1 Discounting Principles: The principle behind "discounting" is that future values are not worth as much as numerically equivalent sums of money held today because money held today, if invested in a bank, would earn interest. Any future value would be larger in numerical terms than it is today. Conversely, future sums can be considered to have been derived from smaller sums upon which interest has been paid. This "cost-today" is, therefore, considered to be numerically smaller than the corresponding cost occurring in the future. This can be represented by a simple formula that produces discounts for a series of annual cash flows, which occur over the life cycle of a program. The net present value (NPV) is simply the total of discounted benefits with the costs having been deducted.

For a series of annual cash values representing the LCC of a system, discounting will reduce the influence of costs the further they occur in the future. If decisions on competing design options are based on comparisons of the NPV, rather than directly on LCC values, then options with high O&S costs are given an advantage. The respective cash flow of the rival options has not been taken into account. When all options meet operational and supportability objectives then the selection must be based primarily on cost. Each option can be evaluated on total LCC both undiscounted and discounted. When the time/cost profiles are very dissimilar, undiscounted and discounted results may be different. Using a cost-based decision, any important operational or supportability differences should be highlighted.

5.4.2 Value Received: Government purchasing policy takes into account the cost of ownership as part of the value for money, by means of an investment appraisal. Investment appraisals (IA) are required as the basis for making decisions on all major government expenditures. IAs are seen as structured approaches in which the objectives of the expenditure are defined, and alternative options are compared. The chosen option has to be shown to be the best value for money. Total costs must be defined and program attributes that cannot be expressed in monetary terms should be listed. A popular misconception is that IAs are concerned only with costs. The need to include effectiveness of the options in the appraisal is particularly important for IAs conducted in the public sector. Operational effectiveness should be compared quantitatively using the results of operational analysis studies. IAs are the focal point for making trade-off decisions between acquisition and ownership costs.