HOW TO ESTIMATE THE INVESTMENT COST OF ELECTRONIC DATA PROCESSING EQUIPMENT

MAY 1966

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Prepared for
COMPTROLLER OFFICE
Cost Analysis Division

ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
L. G. Hanscom Field, Bedford, Massachusetts

Project 800C
Prepared by
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FOREWORD

This report aims to serve two purposes. First, it compiles and documents the methods, techniques, and data sources that can be used to estimate the investment costs of the electronic data processing equipment of Command and Control systems. As such, the report is addressed to the practicing cost estimator. Second, this document is addressed to those concerned with developing new cost-estimating methodology. In this capacity, it presents a format whereby the estimating guidance provided in Chapter 6 of Air Force Manual AFSCL 173-1 (Cost Estimating Procedures)[1] may be applied to estimate the cost of particular items of the Program-Work Breakdown Structure (WBS) (Attachment 1) of the manual. It is believed that similar item-oriented guidance can and should be developed to cover the major "Levels 3, 4, 5, and 6" items of the referenced Structure. For instance, the typical Level 5 items that might be similarly documented are: radar, sensors, computer programming, data display, and communications subsystems of command and control systems; the airframe, propulsion, flight control, navigation aids, and communication subsystems of aircraft systems; space vehicles and re-entry vehicles of space systems; ballistic missile vehicles, training, AGE, and engineering and management of missile systems.

The major thesis of this report is that there are normally several different methods of estimating the costs of any given major Air Force system item, such as EDP equipment. This report describes each of these basic estimating methods, and it discusses under what conditions one method is to be preferred to another.

Many people have generously contributed their specialized knowledge of EDP equipment and its cost estimation during the preparation of this document. The writer is especially indebted to his colleagues in MITRE's Department D-53 (Systems Analysis) and D-84 (Applied Mathematical Analysis) and to personnel in the Cost Analysis Division of the Air Force's Electronic Systems Division.

REVIEW AND APPROVAL

This technical report has been reviewed and is approved.

KENNETH K. WALLICK, Lt. Colonel, USAF
Chief, Cost Analysis Division Comptroller

ABSTRACT

This document seeks to provide practical guidance to analysts charged with estimating the investment costs of the electronic data processing equipment of Air Force Command and Control systems. The document is also offered as a methodological prototype for writing similar item-oriented reports on other major items of Air Force systems, such as communications equipment, radar, sensors, display equipment, computer programming, and the major subsystems of aircraft, ballistic missiles, and space systems.

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SECTION I

INTRODUCTION

DEFINITION

The glossary included in Attachment 1 of the AFSCL 173-1 [1] does not define the term, Electronic Data Processing Equipment (EDP). As a matter of fact, it is not easy to define the term simply or to everyone's satisfaction. One of the problems in definition is in selecting the point of demarcation between EDP equipment and the sensor and communication systems which record and transmit information to the EDP subsystem proper and between the data display systems which make the processed data available in usable form to the manager, decision maker, military planner, design engineer, and other users. Historically, the term "EDP equipment" has not been defined consistently from one cost study to another.

This report will not attempt to resolve the definition issue; actually, the content of the report has not been geared to any single definition of the term. However, because it is necessary to have a general bench mark, EDP equipment is defined to comply with the classification scheme contained in the Work Breakdown Structure (WBS) (Attachment 2 of AFSCL 173-1 [1]). Under this classification, EDP equipment is established as one of the six major item categories of prime mission equipment of a Command and Control system. The other five are: radar, other sensors, computer programming, communications, and data displays. Actually, computer programming, is not an equipment item.

The WBS, in turn, subdivides EDP into four major subclasses: the central processor, large capacity storage, data channels, and input/output equipment. A fifth "catch-all" classification, "other," picks up such items as certain instruction controls and arithmetic elements that do not always fall conveniently into one of the four major classes.

SCOPE OF COSTS COVERED

Only investment or production costs of EDP equipment are discussed in this report. Excluded from this study are:

(a) the RDT & E costs entailed in bringing a new item of equipment from concept to the point of specification;

(b) the development and investment costs of computer programs to be used with the EDP equipment;

(c) the non-production investment costs associated with the EDP equipment such as the costs of installing the equipment and the initial training of personnel to operate the equipment; and

(d) the annual costs of operating and maintaining the equipment once it has been acquired.

MAGNITUDE OF EDP COSTS

Historically, EDP equipment has represented a major item of cost in most Air Force Command and Control systems. The specific magnitude, however, has varied greatly from system to system. Ignoring the upper and lower extremes, EDP equipment costs have generally ranged from 10 percent to 20 percent of total investment costs for most Air Force Command and Control systems.

In most cases, the central processor has been the most costly item of total EDP equipment. Although the situation may vary substantially from case to case, the cost of the central processor has composed roughly one-half of total EDP investment costs. The other three major items, large capacity storage, data channels, and input/output equipment, constitute the remaining 50 percent.

GENERAL PLAN OF THE REPORT

Four basic methods of estimating EDP investment costs are discussed in this report. The advantages and limitations of each method are discussed, and specific data sources that might be referenced in using each method are identified. First, publicly available catalogs are used to a greater extent in costing EDP equipment than they are used in most other major classes of electronic equipment. Second, analogies are widely used in costing EDP equipment just as they are used in costing other items of equipment. In other words, the cost of the EDP equipment of a new system is frequently based on the costs of similar equipment in other prior systems. Third, relatively extensive research has gone into the development of parametric-estimating relationships (ERs) as a means of estimating EDP costs. These ERs will be reviewed. Finally, the paper discusses how the cost estimator can use the help of EDP experts in estimating the investment costs of new EDP equipment.

SECTION II

EDP CATALOGS

TYPES OF CATALOG INFORMATION

Publicly available catalog compendiums provide an extensive array of cost and performance-design data on EDP equipment. These catalogs generally contain the per unit prices for numerous manufacturers' models of EDP equipment.

WHEN CATALOGS CAN BE USED

These catalogs can be used to estimate EDP costs when the equipment to be costed is a standard, off-the-shelf commercial item, and when the office requesting the cost estimate or the system design engineer with whom the cost estimator is working can identify the specific manufacturers' EDP model to be costed. This specific type of equipment description information is likely to be available during Contract Definition (i.e., Definition Phase) or the Acquisition Phase of a System Cycle. Frequently, it will not be known during Concept Formulation (i.e., in the Conceptual Phase).

Although primarily applicable to costing state-of-the-art equipment, catalog prices can also be used as a starting point for costing new types of EDP equipment, which are similar to but slightly more complex or advanced than current manufacturers' specification models. The catalog price would then be a data source for using the "specific-analogy" method of costing discussed in Section III.

ADVANTAGES OF CATALOG COSTING

The catalog method of costing has the following advantages: it is likely to give a more accurate estimate than the Estimating Relationship method of estimation described in Section IV; and its credibility is

relatively easy to establish since its methodology and data sources are easily traced and verified.

DISADVANTAGES OF CATALOG COSTING

There are two closely allied problems associated with using the catalog method of estimating EDP investment costs. Frequently, the cost estimator cannot obtain a model or specification type description of the equipment to be costed. Without such a description, the catalog method of costing cannot be used. Even when a relatively detailed design-type description of the desired equipment is available, there may be a problem in using the catalog method of costing when the equipment to be costed does not match any catalog item. This is often true, especially when the cost analysis is in support of advanced planning projects which require EDP equipment having performance capabilities exceeding the current state-of-the-art. At best, in such situations, the catalog method must be used in conjunction with some of the other estimating methods described in the following sections.

SPECIFIC CATALOG COMPENDIUMS

There are at least five major catalog compendiums of financial and non-financial information on EDP equipment. These are described in Exhibit I.

The choice of a specific catalog source, when it is appropriate to use catalog costing, depends upon a host of considerations. In some circumstances, there is the question of availability. All cost estimators do not have access to all EDP catalogs. Also, some catalogs are easier to reference than others, and when a quick answer is required, the easier-to-reference catalogs may be considered first. Finally, there is the question of accuracy. Accuracy requirements vary from case to case. Some catalog compendiums, because of their greater detail or more frequent updating, will give a more accurate estimate of EDP costs than other compendiums.

EXHIBIT I

EDP Equipment Catalog Compendiums

Document Title	Preparing Agency	Abstract
1. Authorized Federal Supply Schedule Price List for Data Processing Systems for Use by the U.S. Government	Prepared annually for General Services Administration by each EDP manufacturer (U)	Each document specifies the terms under which the particular manufacturer will sell or rent designated models of its EDP equipment to government agencies through the General Services Administration. Describes the performance, design, and operating characteristics of the major equipment plus standard accessories and auxiliary equipment. Cost data provided: purchase prices, monthly rentals, and monthly and hourly maintenance rates.
2. A Survey of Domestic Electronic Digital Computing Systems (BRL-1227)	Dept. of Army Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland (1964) (periodically updated) (U)	Catalogs, under 15 comparative tables or headings, the major performance, design, cost, and related characteristics of 112 domestic electronic digital-computing systems developed since 1961. The major bases of description and comparison are: applications; numerical and arithmetic characteristics; input, output, and storage; construction and checking features; power; space; weight; site preparation and personnel production records; costs and rental rates; sale and lease policy; reliability; operating experience; time availability; engineering modifications; and improvements.

EXHIBIT I (Continued)

EDP Equipment Catalog Compendiums

Document Title	Preparing Agency	Abstract
3. A Third Survey of Domestic Electronic Digital Computing Systems (BRL-1115)	Dept. of Army Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland (1961) (periodically updated) (U)	Primarily of historical interest. Describes 220 domestic, electronic, digital-computing systems developed before 1961. Computers developed subsequent to 1961 are described in "A Survey of Domestic Electronic Digital Computing Systems" (1964). 1,125 pp.
4. Standard EDP Reports (eight volumes with monthly supplements)	Auerbach Corp. Philadelphia, Pennsylvania (U)	Reports in detail on the performance, design, and cost characteristics of all domestic electronic digital computers. Monthly supplements cover new computers of modifications to existing computers. Three features of this publication are notable: (1) comparison charts that report the hardware characteristics, system performance, and configuration rentals of all leading computers; (2) special state-of-the-art reports on specific types of hardware, e.g., high-speed printers, digital plotters, random access storage; (3) very detailed reports on particular computers covering the configuration, performance, and costs of the total system and the major equipment that constitutes the total system. For example, the report on IBM 1410 is over 100 pages.

EXHIBIT I (Concluded)

EDP Equipment Catalog Compendiums

Document Title	Preparing Agency	Abstract
5. Computer Characteristics Quarterly	Adams Associates Bedford, Mass. (issued quarterly)	Catalogs the salient features, including cost, of approximately 200 U.S. and foreign business and scientific computers. Approximately 20 performance or design parameters are indexed for each machine, such as processor speed, storage cycle time, word size, access time, etc. Costs are reported in terms of monthly rental. Both the typical monthly rental and the range of rentals for each machine are usually given.

Furnished free of charge to government agencies, Catalog #1 (G.S.A.) provides the latest, most authoritative prices to the Government of current specification computers. However, if the computer is to be purchased by a government contractor, rather than directly by the Government, GSA prices will probably understate the correct price.

The eight-volume Auerbach reports cost $695 per year and contain more than 5,000 small print, 8-1/2" x 11" pages of detail. These reports are a useful reference to the cost estimator when the system designer can specify a highly detailed description of the EDP equipment configuration to be costed and when a high degree of accuracy in the cost estimate is required. Among the major advantages of the Auerbach reports is that they summarize and consolidate the many thousands of pages contained in the equipment catalogs of different EDP equipment manufacturers. The Auerbach reports also seek to evaluate and rate objectively the comparative capability of different manufacturers' equipment to perform specified EDP tasks. For many costing assignments, however, the cost estimator can work at a higher level of aggregation than that provided by the Auerbach reports.

The major advantage of the Adams Associates catalog is its compact, easy-to-reference format. For instance, the vest-pocket edition of Adams catalog is small enough to fit into a man's shirt pocket and sells for $10 per year for four quarterly issues. It gives the costs and major performance-design parameters of representative configurations of about 200 business and scientific computers. The costs are expressed as monthly rentals, which can generally be converted to approximate purchase prices by multiplying the monthly rentals by a factor between 40 and 50; the exact figure depends upon manufacturer, model, and type of machine. However, the range of costs for a basic computer reported by Adams are, typically, fairly wide because total EDP equipment costs depend so importantly on the specific equipment configuration involved. Hence, when specific EDP configuration des-

criptions are available, the G.S.A. or other, more detailed catalogs should be used.

The Department of Army catalogs (sources 2 and 3, Exhibit I) are much more detailed than the Adams and much less detailed than the Auerbach catalogs. The standard comparative tables which are provided by the Army catalogs, cover both current and superseded computers, and they furnish a good basis for parametric cost studies requiring a broad, historical coverage of performance, design, and cost characteristics. The fact that these documents are available without charge to qualified requestors through the Defense Document Center or the Clearing House for Federal Scientific and Technical Information makes them accessible to practically all estimators who need EDP cost data. An indefinite updating schedule is one drawback of the Army catalogs. There was no 1965 edition, and apparently none is definitely scheduled beyond the 1964 edition.

In addition to the catalogs referenced above, a number of trade magazines, such as Computers and Automation, Business Automation, Electronic News, Datamation, etc., periodically provide catalog-type cost and specification information on major computers.

SECTION III
ANALOGOUS EDP APPLICATIONS

DEFINITION

Sometimes, a cost estimator will base his estimate of the costs of the EDP equipment of a new system on the costs of closely analogous or identical EDP equipment used in some other system(s). These costs from analogous systems may take the form of contractor actuals or of contractor or Air Force estimates for such analogous equipment.

WHEN USED

Analogies are useful as a basis for estimating EDP equipment costs under several circumstances:

(a) One instance would be when the new computer to be costed is a military specification computer or a militarized version of a standard, commercial computer for which there is no standard catalog price.

(b) In some advanced planning or conceptual phase studies, system design engineers may not be in a position to specify a particular manufacturer's model as being the one desired. Occasionally, the engineers may not even be able to specify the general performance requirements (storage capacity, processing speed, etc.) desired of the new computer. Sometimes, the only guidance that the project engineers can give the cost estimator is to liken the type of EDP functions to be performed and the general magnitude of the EDP workload for the new system to those in another specified system. In such instances, the cost estimator's only basis for estimating the EDP costs of the new system is to try to determine what were (have been) the EDP equipment costs of the specified analogous system.

LIMITATIONS

There are several problems in using analogies as an estimating basis. First, no two EDP applications are identical. Sometimes, the analogies suggested by the project engineers, although the best immediately available, may prove to be remote. Even if the engineering aspects of the EDP equipment of the new and old systems are similar, the resource requirements may be vastly different. For instance, the first application may have been plagued by cost-inducing engineering changes that are not likely to occur in later applications. Stated more generally, as equipment evolves from one production level or time period to another, learning curve or price level changes may necessitate major revisions in per unit EDP equipment costs.

Second, it is frequently difficult for the cost analyst to obtain reliable costs on the analogous EDP application. Very often, the only costs obtainable on the analogous application are estimated costs as opposed to actual costs. There are several reasons for this. First, historically, on many contracts the Air Force has not received item-by-item breakdowns of contractor actuals. (Under the new AFSCL 173-2 Cost Information System, item-by-item breakdowns of contractor actuals may be provided more frequently than in the past.) Second, when the item cost actuals do become available, they are often treated as highly proprietary and are not available to cost estimators at all echelons and in all organizations. Third, it is sometimes hard to evaluate the validity and applicability of the item cost actuals reported. For instance, the term, "EDP investment cost," is not always defined in the same way by a contractor as it is by an Air Force cost analyst.

Thus, because actual cost data are often hard to obtain, the specific analogy method of estimation, historically, has often involved using a prior cost estimate as a base to make a future cost estimate.

This procedure is hazardous simply because, historically, many prior estimates have been seriously in error.*

PINPOINTING SIMILARITIES AND DIFFERENCES

Notwithstanding the problems in using the specific analogy method of estimation, it is very frequently used by cost estimators since the problems in using other estimating methods are often even more difficult. There are various data sources that can be employed in using the specific analogy method to estimate EDP investment costs.

MITRE has made studies which can aid the cost estimator in determining how similar a new EDP equipment requirement is as compared to previous or contemporary EDP equipment on which he has cost data. [2,3]

These studies, which were undertaken to assist the Air Force in procuring EDP equipment, list among other things several hundred performance or design parameters of EDP equipment that may influence the cost as well as the effectiveness of such equipment. Illustrative of such parameters are: the size, access time, cycle time, etc., of the main memory unit of the central processor, the storage capacity, access time, minimum addressable record length, etc., of the intermediate access storage (disk, drum, magnetic tape). Among the more general physical parameters of the total EDP equipment system are weight, cubage, power requirements, etc. Even more general are: ease of maintenance, survivability, security provisions, etc.

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* A number of studies (RAND, Peck & Sherer, etc.) have quantified this error. Charles J. Hitch, former Department of Defense Comptroller, recently stated: "There is first the problem of estimating the development and production costs of new weapon systems. The record of the Department over the past fifteen years has been spectacularly bad. We and our contractors have typically underestimated costs by factors of two to ten. (Not 2 to 10 percent, but 100 to 900 percent.)" Charles J. Hitch, Decision-Making for Defense, University of California Press, 1965, p. 64

As indicated above, the referenced MITRE studies provide checklists for systematically identifying the areas of cost-inducing differences in performance and design between proposed or new EDP equipment and previous or contemporary EDP equipment.

SPECIFIC ANALOGIES

A useful source for learning what types of EDP equipment particular agencies of the Federal Government (military and non-military) are using, what the costs of these equipments are, where each specific item of EDP equipment is located geographically, and to what applications these equipments are being put are reported in Inventory of Automatic Data Processing (ADP) Equipment in the Federal Government. [4]

A useful source for finding out what types of EDP equipment the Air Force is currently using at specific Air Force bases and for what purposes or to what applications this equipment is being put is Data Systems Automation Program. [5]

A limitation of these sources is that their data is approximate and partial rather than precise and complete. Costs are coded in broad ranges; it is difficult to associate the equipment applications to particular "L" systems; the geographic locations are approximate (e.g., MITRE's location is stated as Framingham rather than as Bedford), and only the basic computer is identified rather than the full EDP configuration.

SECTION IV

COST-ESTIMATING RELATIONSHIPS

TYPES OF CERs

Both the Air Force and its not-for-profit technical support contractors have developed Cost-Estimating Relationships (CERs) that may be used under limited circumstances to estimate certain EDP equipment costs.

These CERs are equations which provide the means for estimating the investment costs of a unit of EDP equipment based on the values of one or more of the equipment's performance parameters such as storage cycle time, complete add time, minimum core storage capacity, etc.

WHEN THESE CERs MAY BE USED

These CERs may be used to estimate EDP costs when the cost estimator is able to secure only a very limited description of the equipment that he is to cost; when he is able to learn only what the performance capabilities of the equipment are to be, not what it will look like, the nature of its design, its specification number, or the manufacturer's model number. Usually, this limited information is likely to be available during a system's Concept Formulation. Limited description information may also be available beyond the Concept Formulation when the computer required is different (somewhat advanced) from any current specification computer. Under such circumstances, especially if the time available in which to make the estimate is very short, the use of parametric CERs may be a valuable means of getting a rough estimate of a new computer's cost.

A parametric CER also can provide a quick, simple means of double-checking the estimate derived by other estimating methods.

LIMITATIONS OF CERs

Since considerable research effort has been spent in developing parametric CERs for EDP equipment, and since even greater effort is in process in developing such CERs in all fields of military costs, it is appropriate to consider here the problems and limitations relative to using such CERs

One, the relatively limited set of circumstances under which a parametric EDP CER is the preferred method of estimation is one of the severest limitations of this estimating method. Where specification type description information is available, a catalog price or a specific EDP analogy will normally provide a more accurate estimate. Where only task-workload type information is available, EDP CERs that have been developed to date cannot be used; a specific task-workload analogy must be found.

Two, even when the conditions are propitious for using parametric CERs, they must be used with great discretion. In the EDP field, the pace of technological progress is rapid, and there is a longrun trend of greater overall computing power per dollar spent. To cite a dramatic example, Diebold recently forecast that for typical "chip systems" image files the cost per unit stored will decline from $1.00 in 1964 to $0.60 in 1966 to $0.004 in 1973. [6] What this means is that, wherever advanced developments are concerned, CERs based on historical costs must be adjusted for the longrun declining cost factor. To determine this adjustment factor, the cost analyst should check with experts in particular fields of EDP technology.

In addition to these general precautions, several other reservations should be made relative to the available parametric CERs on EDP equipment. First, two of the organizations (System Development Corporation and RAND Corporation) that have tried to develop parametric CERs for EDP equipment arrived at essentially inconclusive or negative

findings. SDC found no consistent, reliable relationship between EDP cost and EDP performance parameters, whereas RAND imposed severe limitations on the EDP CER it developed. [7,8]

Another qualification is that most EDP CERs have been based predominantly on general purpose computers. Frequently, however, Air Force Command and Control systems require special purpose computers or a special adaptation of general purpose computers.

Finally, no CER covering total EDP investment costs (WBS Level 5) has been developed by anyone. The CERs developed to date have covered either the central processor or large capacity storage units. None has been developed covering data channels, input-output equipment, or other miscellaneous EDP items.

Conceivably, it might be possible to estimate these latter three categories of EDP equipment as a factor or percentage of the central processor and large capacity storage costs. However, no one to date has developed such an ER. RAND, which has worked on EDP CERs, cautions against expectations for such cost-to-cost CERs because the peripheral equipment configuration varies so drastically from one EDP application to the next. Rapidly advancing technology also makes it difficult to establish any stable relationship between one type of EDP cost and another. For instance, Diebold estimates that between 1963 and 1973 the cost of the main frame and operating memory will decline from 53 percent to 21 percent of total EDP costs in a typical manufacturing plant. [6]

SPECIFIC CERs

(a) AFSC (ESD) has developed two major EDP parametric CERs. The first [9] is:

$$Y_c = \left[17.20\ (X)^{-0.1479}\right]^3;$$

Y_c = the acquisition cost of the central processor in millions of dollars;

X = the speed of the equipment defined as the time, in microseconds, required to execute an add instruction or a given sequence of arithmetic or logical instructions including the storage access time.

The coefficient of correlation for the estimating equation is 0.745, and the standard error of estimate is 0.0775.

The second ESD EDP CER [10] is:

$$Y_c = 1{,}734\ (X)^{0.8726};$$

Y_c = the acquisition cost in dollars of the EDP magnetic core storage unit;

X = the storage capacity of the memory unit in binary digits (bits) divided by 1000.

The coefficient of correlation of the estimating equation is 0.9752, and the standard error of estimate is 0.1020.

The ESD CERs apply to computers bought by the Federal Government. Computers bought by military contractors would probably be somewhat higher in price.

(b) RAND has developed the following CER [8]:

$$R = 0.37 + .033\ (cyc) + .015M;$$

R = monthly rental in thousands of dollars of the equipment group composed of the central processor, memory, and associated control modules;

cyc = the number of memory cycles per second, in thousands (the reciprocal of cycle time);

M = memory core capacity in M bits.

RAND cautions that the referenced equation does not closely fit the observations used to derive it, especially for smaller machines. The coefficient of correlation of the estimating equation is 0.91.

(c) MITRE has developed a series of eight EDP CERs as shown in Exhibit II.[11] These CERs provide the basis for computing the cost of the computer central complex using minimum core storage capacity and/or complete add time as the independent variables. The estimating equations were derived from observations taken on 15 computers in the field in 1963. The MITRE CERs apply to general purpose, digital computers having greater than 100,000 bits minimum core storage capacity and with a central processor cost exceeding $300,000.

(d) The Diebold Group, Inc., computer research consultants, has provided a series of ERs oriented toward future EDP developments. The Diebold study represents an intensive three-year project in which 80 large U.S. and European corporations have participated. One of the Diebold summary charts is reproduced as Exhibit IV. These types of projected factors, which represent a distillation of expert opinions (see Section V), may be quite useful to an estimator for obtaining a "quick fix" on the likely financial impact of specific new developments in EDP technology. Two qualifications, however, apply to these ERs. First, the ERs have been formulated at a lower level of item detail than many Air Force cost estimators are accustomed to working. Second, such factors inherently have a strong subjective basis and can provide, at best, only a highly gross estimate.

EXHIBIT II

MITRE EDP CERs

ER Formula	Coefficient of Correlation (r)	Level of Statistical Significance	Standard Error of Estimate
$\log_{10} C = 6.45-0.939 \log_{10} SCT$	-0.857	$P < .01$	5.159 (in $\log_{10}$ \$)
$\log_{10} C = 6.25-0.396 \log_{10} CAT$	-0.783	$P > .10$	5.280 (in $\log_{10}$ \$)
$\log_{10} C = 1.97+0.701 \log_{10} MCSC$	+0.871	$P < .01$	5.158 (in $\log_{10}$ \$)
$\log_{10} C = 6.44-0.980 \log_{10} SCT+0.064 \log_{10} CAT$	-0.859	$P < .01$	5.166 (in $\log_{10}$ \$)
$C = 1,200,000-146,000SCT+0.687MCSC$	+0.968	$P < .01$	246,000 (in \$)
$C = 677,000-23,800CAT+0.831MCSC$	+0.934	$P < .01$	344,000 (in \$)
$C = 803,000-160,000SCT+101,000CAT+0.779MCSC$	+0.981	$P < .01$	203,000 (in \$)

C = Cost of Central Complex in \$

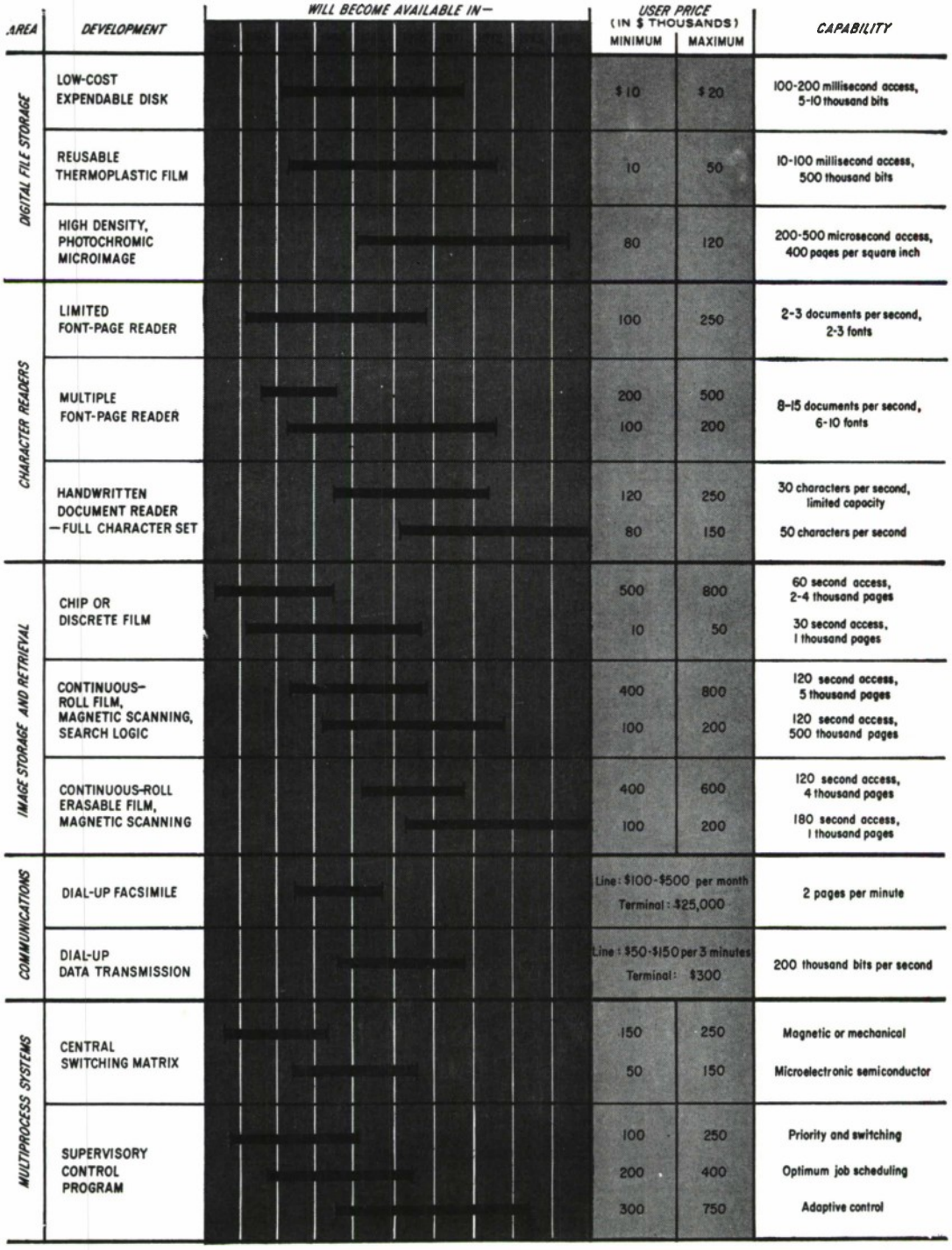
SCT = Storage Cycle Time in Microseconds

MCSC = Minimum Core Storage Capacity in Bits

CAT = Complete Add Time in Microseconds

EXHIBIT III

INFORMATION-PROCESSING DEVELOPMENTS - SELECTED TECHNICAL PROJECTIONS



AREA	DEVELOPMENT	WILL BECOME AVAILABLE IN—	USER PRICE (IN $ THOUSANDS) MINIMUM	USER PRICE (IN $ THOUSANDS) MAXIMUM	CAPABILITY
DIGITAL FILE STORAGE	LOW-COST EXPENDABLE DISK		$ 10	$ 20	100-200 millisecond access, 5-10 thousand bits
	REUSABLE THERMOPLASTIC FILM		10	50	10-100 millisecond access, 500 thousand bits
	HIGH DENSITY, PHOTOCHROMIC MICROIMAGE		80	120	200-500 microsecond access, 400 pages per square inch
CHARACTER READERS	LIMITED FONT-PAGE READER		100	250	2-3 documents per second, 2-3 fonts
	MULTIPLE FONT-PAGE READER		200 100	500 200	8-15 documents per second, 6-10 fonts
	HANDWRITTEN DOCUMENT READER —FULL CHARACTER SET		120 80	250 150	30 characters per second, limited capacity 50 characters per second
IMAGE STORAGE AND RETRIEVAL	CHIP OR DISCRETE FILM		500 10	800 50	60 second access, 2-4 thousand pages 30 second access, 1 thousand pages
	CONTINUOUS-ROLL FILM, MAGNETIC SCANNING, SEARCH LOGIC		400 100	800 200	120 second access, 5 thousand pages 120 second access, 500 thousand pages
	CONTINUOUS-ROLL ERASABLE FILM, MAGNETIC SCANNING		400 100	600 200	120 second access, 4 thousand pages 180 second access, 1 thousand pages
COMMUNICATIONS	DIAL-UP FACSIMILE		Line: $100-$500 per month Terminal: $25,000		2 pages per minute
	DIAL-UP DATA TRANSMISSION		Line: $50-$150 per 3 minutes Terminal: $300		200 thousand bits per second
MULTIPROCESS SYSTEMS	CENTRAL SWITCHING MATRIX		150 50	250 150	Magnetic or mechanical Microelectronic semiconductor
	SUPERVISORY CONTROL PROGRAM		100 200 300	250 400 750	Priority and switching Optimum job scheduling Adaptive control

SOURCE: The Diebold Research Program.

Taken from Harvard Business Review, September-October 1965

SECTION V

EDP EXPERTS

COST APPLICATIONS OF EDP EXPERTISE

Experts in various areas of EDP technology are frequently useful to the cost estimator in estimating the EDP equipment costs of a new system. First, such experts may help the cost estimator surmise the design implications of a new, enhanced EDP performance requirement. For instance, the EDP engineer may provide an informed opinion as to what effect on the equipment's size, weight, internal circuitry, etc., that a 100 percent increase in the data-processing rate or internal memory capacity would have. Second, the EDP experts may provide the cost estimator with an engineering estimate relative to the effect of changes in engineering complexity, in size, or in weight of the equipment on per unit EDP investment costs.

WHEN TO USE EXPERTS

EDP equipment experts are likely to be useful consultants to the cost estimator under several sets of circumstances.

(a) When the new computer to be costed necessitates a new, complex development in technology over and above that embodied in any current specification computer, experts may provide more up-to-date, relevant guidance on both configuration and costs than that afforded in published catalog prices or parametric CERs based on state-of-the-art equipment.

(b) When other methods of estimating the cost of new EDP equipment, such as catalog prices, parametric CERs, contractor actuals, or estimates on the costs of analogous equipment, are in sharp conflict relative to the appropriate estimated

cost of the new computer, a recourse to experts may help to resolve or compromise the conflict.

(c) When the time available in which to estimate the EDP costs is too short to locate and analyze catalog prices, contractor records, or parametric CERs, the estimator can often quickly obtain an order-of-magnitude cost estimate for the new computer from an expert who is in close, constant touch with the latest developments in the EDP field.

LIMITATIONS

The most frequent problem in using experts is that the cost estimator often receives little or no traceable supporting data or methodology to substantiate the expert's opinion. Of course, sometimes an EDP expert will support his "considered" opinion with full documentation that traces each step of his reasoning. However, in many cases expert opinions are purely intuitive, and the cost estimator receives little or no insight relative to the process that the expert used to reach his opinion. The problems of evaluating such undocumented opinions are heightened by the fact that many of the most knowledgeable computer experts are employed by the leading manufacturers of computer equipment. It is reasonable to presume that the opinions of these experts are sometimes slanted to reflect favorably on the computers manufactured by or being developed by their employers.

Another problem in using outside experts for opinions is that project ground rules sometimes deny Air Force cost estimators access to contractor sources when making "independent" Air Force cost estimates.

SOURCES OF EDP EXPERTISE

AFSCL 173-1, (pp. 4-10 and 4-11)[1] establishes as a longrun project the preparation of an "Expert Source Record" (AFSC Form 12) for all major items of Air Force systems. The following provides a start toward a "Hanscom Complex" EDP expert list:

(a) Air Force Sources

1. ESD, Directorate of Technology, Computer Division
2. ESD, EDP Equipment Office
3. ESD, Comptroller, Cost Analysis Division (for cost data)

(b) The MITRE Corporation

1. Department 71, Computer & Display Technology
2. Department 84, Applied Mathematics (for technical characteristics of EDP equipment affecting cost)
3. Department 53, Systems Analysis (for cost data)
4. Division 5, Planning Staff

(c) Industrial Sources

The publicly available manufacturers' catalogs plus Air Force contractor records provide relatively thorough guidance as to which companies are manufacturers of and experts for particular types of computers. Air Force cost estimators have several means of identifying particular departments or individuals within these companies as experts on particular computer areas. First, either of the Air Force EDP expert sources, identified in (a) and (b) above, can provide useful guidance on this matter. Second, the U.S. Organization Chart Service, a private quarterly publication, identifies the major departments and personnel of all leading industrial companies, including EDP manufacturers. Also, private EDP evaluative organizations, such as Auerbach, Diebold, and Adams Associates, have a good working knowledge of industrial expertise for EDP equipment, plus a substantial in-house capability on their own staffs.

SECTION VI

SUMMARY

This report has tried to show that a cost analyst who estimates EDP equipment costs has at his disposal a kit of estimating tools rather than a single method. Also, it has been stressed that none of the various estimating methods has an inherent, universal, clear-cut advantage over the others. In any given case, the preferred estimating method will depend upon many considerations such as: how well (how specifically) the EDP equipment to be costed is described; the types of documented data plus expert sources available to the estimator; whether or not a high degree of accuracy in the cost estimate is important; and the length of time the estimator has to make his estimate.

Frequently, because of data inadequacies and other problems, the analyst will find it advantageous to use two or more methods to estimate EDP equipment costs, even if a second or third method is used only to check the results provided by the first.

Exhibit III provides a highly simplified, generalized cost-estimating matrix that attempts to recap procedurally the salient features of this report.

Finally, note should be made of the need for further and continuing work in this area of EDP cost-estimating methodology. This work should be of three types:

(a) First, there is the question of normal updating. Some of the specific content of the report is relatively perishable. New catalog services, new estimating relationships, new experts, and new analogous EDP applications will certainly become available. Periodically, a document of this type should be revised to reflect such new information.

EXHIBIT IV

A Generalized Cost-Estimating Matrix

Item Description A	Cost-Estimating Method B	Procedures C
I. Task Oriented A cost estimate is requested at a point in time when only a statement of the types of EDP tasks* and some quantitative measure of the EDP workload† to be performed is known. EDP performance requirements (add time, cycle time, bulk storage capacity, etc.) are not yet known. No information is yet available on EDP equipment specifications or manufacturer's model numbers.	Specific Analogies Expert Sources Catalog Prices	1. Identify an EDP requirement of another prior system or project that resembles the new EDP application relative to types of EDP tasks and workloads to be performed. If necessary, and if possible, consult with system design engineers and EDP experts in selecting appropriate analogies. 2. Ascertain the types (manufacturer's models) of EDP equipment used in the analogous system.

* Status monitoring, reprogramming, retargeting, surveillance, detection, identification, interception, etc.

† Status monitoring - 1000 weapons in "near" real-time.
Interception - simultaneously perform 25 intercepts.
Detection - 0.999 probability, m^2 target.

EXHIBIT IV (Continued)

A Generalized Cost-Estimating Matrix

Item Description A	Cost-Estimating Method B	Procedures C
I. Task Oriented (continued)		3. Determine the costs of such analogous equipment by: (a) checking contract or other records covering the prior application; (b) consulting available EDP catalogs for standard costs of such equipment (see Exhibit I). 4. Adjust contract, catalog or other bench mark cost data to reflect differences between the new and the analogous EDP equipment relative to: (a) tasks and workloads to be performed; (b) implied or projected equipment characteristics emanating from tasks and workload differences; (c) learning curve phenomena to reflect possible increases in production levels;

EXHIBIT IV (Continued)

A Generalized Cost-Estimating Matrix

Item Description A	Cost-Estimating Method B	Procedures C
I. Task Oriented (continued)		4. (d) price level changes from one time period to another. EDP experts may be consulted for guidance relative to 4a, b, & c.
II. Performance Oriented A cost estimate is requested at a point in time when design engineers have translated the general EDP tasks and workloads to be performed into a statement of specific performance requirements demanded of the EDP equipment: e.g., minimum core storage capacity = 50,000,000 bits; complete add time = 1.5 microseconds, etc. No information is yet available on the equipment specification or manufacturer's model(s) that will be used to meet these requirements.	Specific Analogies Expert Sources Catalog Prices Estimating Relationships	1. Follow procedures specified in I.C. 2. Double-check estimate provided through II.C 1 above against estimate provided by any EDP ERs available. 3. If time or other constraints preclude following procedure specified in I.C, estimate EDP costs by using EDP ERs.

EXHIBIT IV (Concluded)

A Generalized Cost-Estimating Matrix

Item Description A	Cost-Estimating Method B	Procedures C
III. Specification Oriented A cost estimate is requested at a point in time when design engineers have been able to designate a government specification item or a particular manufacturer's model of EDP equipment as being required.	Specific Analogies Expert Sources Catalog Prices	1. Determine the historical or standard per unit costs of such EDP equipment as follows: (a) ascertain in the manner described in I.C the contract or other costs of this particular model equipment as used in other analogous systems; (b) check prices listed in EDP catalogs described in Exhibit I. 2. Adjust prices derived in III.C 1 above following the procedures prescribed in I.C 4.

(b) Second, the technique and data source portions of the report could profitably be expanded:

(1) Certain methodological issues recently explored in a generalized context should be discussed in the specific context of estimating EDP equipment costs, for instance: how should an analyst proceed when he has several more or less analogous EDP sources; how should he select consultants or experts in particular EDP areas; and how should he comparatively evaluate a host of heterogeneous EDP data sources to arrive at a final cost estimate that gives due consideration to all of his available information.*

(2) A later edition of the report will expand the specific-analogue guidance discussed in Section III relative to computers used in Air Force Command and Control systems.

(3) A later edition will also incorporate the data that will be collected on AFSC Forms 12, Expert Source Record, relative to EDP experts.

(4) Similar item-oriented, cost-estimating guidance reports will be written on computer programming and on EDP equipment development and operating cost estimating.

(c) Finally, a future revision of this report will include a case study that will illustrate in a step-by-step, real-life context how an analyst should use the techniques and information sources discussed in this report.

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* For a brief, general discussion of these issues, see: AFSC L 173-1, Cost Estimating Procedures, Chapter 4, Sections C and D; [1] and M. V. Jones, Estimating Methods and Data Sources Used in Costing Military Systems, MITRE TM-4263, June 1965, 33-45.

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13. ABSTRACT

This document seeks to provide practical guidance to analysts charged with estimating the investment costs of the electronic data processing equipment of Air Force Command and Control systems. The document is also offered as a methodological prototype for writing similar item-oriented papers on other major items of Air Force systems, such as communications equipment, radar, sensors, display equipment, computer programming, and the major subsystems of aircraft, ballistic missiles, and space systems.

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