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COMPUTER FAMILY ARCHITECTURE SELECTION COMMITTEE FINAL REPORT. --ETC(U)
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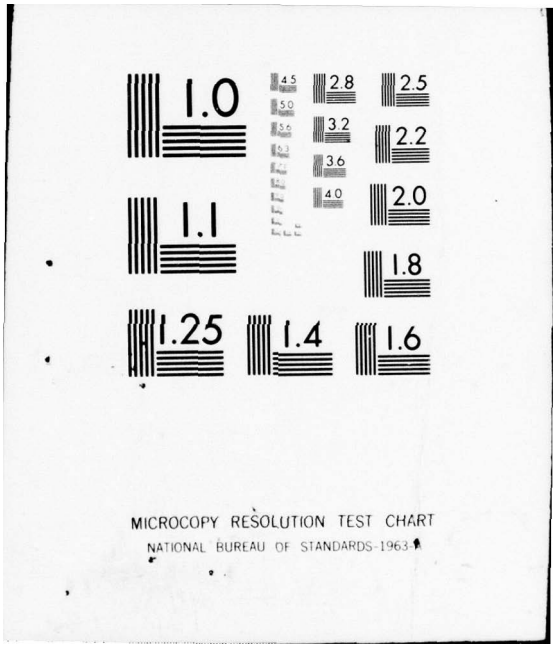
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COMPUTER FAMILY ARCHITECTURE SELECTION COMMITTEE - FINAL REPORT, VOLUME VI - LIFE CYCLE COST MODELS

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17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

18. SUPPLEMENTARY NOTES
This report consists of a summary and nine (9) volumes. It is the result of joint Army/Navy work. The complete report may be separately published by the Naval Research Laboratories.

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*
Computer Family Architecture, BOTTOM-UP MODEL, TOP DOWN MODEL, Life Cycle Cost.

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*
This report describes the mathematical information, input data, and results of a methodology and two life-cycle requirements models for comparing computer architectures with respect to life-cycle costs: the Top Down (TD) model and the Bottom-Up (BU) model. The methodology and models were formulated to help the Army and Navy select a single computer architecture for a software-compatible family of military computers for the 1980's. Three candidate architectures were compared: The IBM System/370, the Digital Equipment Corporation PDP-11, and the Interdata 8/32. The data derived using the BU model indicates that the PDP-11

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20. architecture would be the most cost-effective architecture for the military embedded computer environment in most circumstances. The data derived using the TD model indicates that for software-to-hardware cost ratios greater than about one the IBM 370 architecture is superior, for ratios less than about one fourth the Interdata 8/32 architecture is best, and for ratios in between the PDP-11 architecture is most desirable. The differences in the results of the models are explained in terms of uncertainties in the input data, and the debatable validity of some of the model's assumptions.

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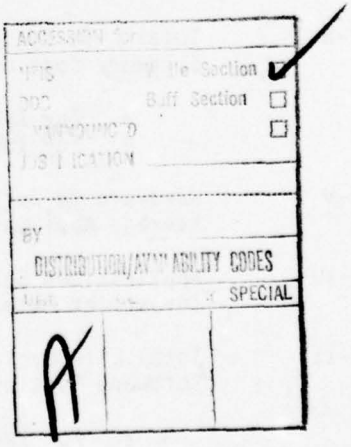

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1. INTRODUCTION/BACKGROUND

a. INTRODUCTION

The final report of the Army/Navy Computer Family Architecture (CFA) Selection Committee consists of nine volumes, which together describe the background, activities, and technical findings leading to the recommendation by that Committee for a computer architecture to be used in a family of software-compatible military computers. This is the sixth volume of that report. It describes the methodology used to compute life-cycle costs of military computer implementations based on CFA candidates and it presents the results of applying this methodology to two different life-cycle models.

Volume I explains the background, rationale and organization of the Computer Family Architecture (CFA) effort.

Volume II describes the technical issues addressed by the Selection Committee for preliminary evaluation of the architecture candidates and describes the results of that technical evaluation.

Volume III describes test program specification and development and the application of these test programs to evaluation of architectural efficiency of CFA candidates.

Volume IV presents hardware language (ISP) descriptions of the candidate architectures and describes the ISP interpreter facility used to simulate and gather data from the test program runs.

Volume V addresses the determination of support software requirements and the evaluation of the available support software of the candidate architectures with respect to these requirements.

Volume VII addresses the financial, technical, and legal issues arising out of discussions with the owner/manufacturers of the candidate computer architectures and describes the outcome of these discussions.

Volume VIII describes the considerations of the Selection Committee during the final selection process and the synthesis of the architecture evaluation on data that formed the basis for the final selection.

Volume IX addresses controversial issues and questions that arose during the course of the CFA effort.

The two life-cycle models described in this volume are called the Bottom-Up (BU) and Top-Down (TD) models. These models were originally described in two separate internal reports (SvirW76a), (CornJ76a). This volume merges and elaborates on those reports.

Section 2 describes the mathematical formulation, input data, and results of the BU model. This model was developed and its results computed by William R. Svirsky, Al Irwin, and Tom Giles of System Development Corporation, West Long Branch, New Jersey, under the sponsorship and direction of Aaron H. Coleman of the U. S. Army Electronics Command, Ft. Monmouth, New Jersey. William Svirsky wrote most of the description contained herein.

Section 3 describes the mathematical formulation, input data, results and error analysis of the TD model. John J. Cornyn and William R. Smith of the Naval Research Laboratory formulated the model. J. Cornyn carried out the computations on the NRL PDP-10 timesharing system and wrote most of the text.

Three candidate architectures were compared using the models: the IBM 370, the Digital Equipment Corporation PDP-11, and the Interdata 8/32. The BU model predicted that the PDP-11 architecture would be the most cost-effective architecture for the military embedded computer environment in almost all circumstances. The TD model predicted that for software-to-hardware ratios greater than about one, the IBM 370 architecture is superior, for ratios less than about one-fourth the Interdata 8/32 architecture is best, and for ratios in between the PDP-11 architecture is desirable. Section 4 discusses the results of the models and explains the differences on the basis of uncertainties in the input data and the debatable validity of some of the models' assumptions.

R. P. Estell, of the Fleet Combat Direction Systems Support Activity, San Diego, California, and Capt Robert P. Sabin, Project Manager of the SAM-D Missile System, Redstone Arsenal, Alabama, contributed to the formulation of the life-cycle cost methodology.

b. BACKGROUND

At the third meeting of the CFA Selection Committee, on 18-20 February 1975, at the Naval Postgraduate School, Monterey, California, Dr. Bruce Wald (NRL) addressed the Selection Committee. He urged that final selection of the CFA be based on considerations meaningful and convincing to DoD management, in particular the cost benefits/penalties of the various choices. Consequently, a Final Selection Methodology Subcommittee was established (R. Estell (FCDSSA), R. Sabin (SAM-D), and W. Smith (NRL), chairman) to develop a methodology for including cost considerations in the final CFA selection.

At the fourth Committee meeting on 28-29 February at NRL, Washington, D.C., W. Smith presented the methodology developed by the Final Selection Methodology Subcommittee [EsteR76]. This methodology provided the approach to convert computer resource requirements (processor performance, storage, software) into dollar costs and to derive those costs for the life-cycle requirements of relevant military computer uses. In particular, he proposed that this methodology be applied to a model (later designated as the top-down (TD) model) of military computer requirements, based on extrapolating trends in DoD computer resource requirements and expenditures. The Committee accepted this approach.

Subsequently, at a meeting at USAECOM, Ft. Monmouth, N.J., A. Coleman (ECOM) proposed to W. Smith that an additional computer resource requirements model (later designated as the bottom-up (BU) model), complementary to the TD model, be used to compute military computer life-cycle costs. The BU model was based on specific, individual computer systems in existing or planned Army applications. The System Development Corporation (SDC), under contract to ECOM,

was available to perform the BU data gathering and computations. Since it was believed that the use of both the TD and BU models would help to check the consistency and validity of the results, it was agreed that both results would be presented to the Selection Committee at its fifth and final meeting in August 1976.

In order to assist the reduction of software requirements to costs, it was further agreed that SDC would attempt to gather data from software development projects in SDC and to formulate a support-software-availability/software-development-cost relationship from that data. The results were subsequently used in the reduction of both models to life-cycle costs.

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CornJ76a Cornyn, J. J., "A Life Cycle Cost Model for Comparing Computer Architectures," Naval Research Laboratory, Washington, D.C., October 6, 1976 (unpublished manuscript).

EsteR76 Estell, R. G., Sabin, R. P., and Smith, W. R., "Final CFA Selection Methodology Subcommittee Preliminary Report," April, 1976.

SvirW76a Svirsky, W. "Life Cycle Cost Analysis of Computer Family Architecture (CFA) Finalists with Army Embedded Computer Systems," System Development Corporation, West Long Branch, New Jersey, SDS CENTACS Customer Produce #43, September, 1976 (unpublished manuscript).

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a. INTRODUCTION

b. BACKGROUND

c. BASIC APPROACH

d. RESULTS

e. SUMMARY/CONCLUSIONS

f. REFERENCES

g. APPENDIX - TABLES

2. THE BOTTOM-UP MODEL

a. INTRODUCTION

Section 2 provides the results of a life-cycle cost analysis of three competing architectures - IBM 370, DEC PDP-11, and Interdata 8/32- as applied to fifteen current Army embedded-computer systems.

As indicated in the Table of Contents, Section 2 discusses the background events leading to the initiation of this analysis, describes the basic approach or methodology used, tabulates the results obtained and presents the conclusions.

b. BACKGROUND

At the 4th meeting of the CFA Selection Committee on 28/29 April 1976 at NRL, Washington, D. C., W. Smith (NRL) presented a methodology for quantitative/relative evaluation of the life-cycle costs of the DOD computer resource requirements as a function of the three CFA finalists under consideration (EsteR76). In addition, a model (later designated as the top-down (TD) model) of military computer resource requirements, based on projections of trends in military computer resource expanditures and requirements, was proposed to be used in conjunction with the methodology for computing life-cycle costs. Subsequently, A. Coleman (ECOM CENTACS) proposed a complementary requirements model (later designated as the bottom-up (BU) model) for military computer resources based on specific, individual embedded-computer systems (ColeA76a). At a meeting on 17 May 1976 involving personnel from NRL, ECOM (CENTACS) and SDC, it was agreed that the life-cycle cost analyses to be presented to the CFA Selection Committee at its 5th meeting in August 1976 would include both the TD and BU models (ColeA76b). At this meeting, a model prepared by SDC for CENTACS (SvirW76b) was amended to serve as the basis for the BU model described in this report.

c. BASIC APPROACH

(1) Overview

The computer resource life cycle cost was estimated for each of 15 Army embedded-computer systems (employing each of the three CFA finalists) and for all systems. Estimates were made for 1976 and for 1985 production procurements. The lowest cost CFA for each system and for all systems was selected for 1976 and 1985 procurements. The systems are designated #1 to #15 and are listed in Table 2-1. As shown in Table 2-1 these systems are in various phases of their life cycle.

(2) Total Life Cycle Cost

The computer resource life cycle cost for a given system and a specific CFA is defined as:

$$C_{ij} = Hw_{ij} + ASw_{ij} \qquad (2.1)$$

where C_{ij} = computer resource life cycle cost of system i using architecture j

TABLE 2-1

Army Embedded - Computer Systems

SYSTEM #	SYSTEM MISSION	LIFE CYCLE PHASE
1	Medium Search	Engineering Development
2	Medium Command & Control	Initial Production
3	Small Search	Conceptual Phase
4	Large Command and Control	Limited Production
5	Medium Command and Control	Advanced Development
6	Large Command and Control	Advanced Development
7	Small Command and Control	Advanced Development
8	Large Communications	Engineering Development
9	Small Communications	Engineering Development
10	Small Communications	Advanced Development
11	Small Special Purpose	Engineering Development
12	Large Data Management	Deployment
13	Medium Search	Advanced Development
14	Medium Data Management	Conceptual Phase
15	Small Guidance and Control	Conceptual Phase

Hw_{ij} = hardware life cycle cost of system i using architecture j

ASw_{ij} = applications software life cycle cost of system i using architecture j

(3) Hardware Life Cycle Cost (LCC)

(a) Total Hardware LCC

The computer hardware life cycle cost for a given system using a specific CFA is defined as:

$$Hw_{ij} = n_i L_h (P_{ij} + MM_{ij} + SM_{ij}) \qquad (2.2)$$

where

n_i = number of units to be produced for system i

L_h = hardware life cycle cost factor, i.e., ratio of total hardware life cycle cost to hardware acquisition cost. This factor is assumed to be 2 for a 10-year life cycle

P_{ij} = processor acquisition cost for system i using architecture j

MM_{ij} = main memory acquisition cost for system i using architecture j

SM_{ij} = secondary memory acquisition cost for system i using architecture j

(b) Processor Acquisition Cost

The processor acquisition cost for system i using architecture j is defined as:

$$P_{ij} = K(a_{ij} Mr_i)^{0.4} \qquad (2.3)$$

where

K = constant relating to processor cost, derived as shown below

a_{ij} = processor speed ratio for architecture j for system i derived from architecture test data as described in the Appendix, Section 2.7

Mr_i = operating speed in MIPS* required for system i, derived from system proponents

*MIPS = millions of instructions per second

Equation (2.3) and Ko are derived in [SvirW76b] from equation (2.4) below;

$$Ma_{ij} = Ko\ (cost)^{2.5} \tag{2.4}$$

$$\text{or} \quad Ko = \frac{Ma_{ij}}{(cost)^{2.5}} \tag{2.5}$$

$$\text{where} \quad Ma_{ij} = a_j\ Mr_i \text{ stated in MIPS} \tag{2.6}$$

$$\text{thus} \quad Ko \text{ is the ratio } \frac{MIPS}{(cost)^{2.5}} \tag{2.7}$$

Examination of recent cost/speed data for several military processors shows that speeds of 0.5 MIPS and corresponding processor costs of $48,000 are representative values. Substituting these figures into equation (2.7) yields a value of:

$$Ko = 9.9x10^{-13}$$

Equation (2.4) can be restated in terms of cost, P_{ij}, as:

$$P_{ij} = \left(\frac{Ma_{ij}}{Ko}\right)^{0.4} \tag{2.8}$$

$$\text{substituting } K = \left(\frac{1}{Ko}\right)^{0.4} = \left(\frac{1}{9.9x10^{-13}}\right)^{0.4} = 6.3x10^{4} \tag{2.9}$$

This value of K is used in subsequent calculations for 1976 processor cost estimates and is reduced by a factor of 10 for 1985 processor cost estimates based on an assessment of hardware cost reduction over the next decade.

(c) Main Memory Acquisition Cost

The main memory acquisition cost for system i using architecture j is defined as:

$$MM_{ij} = c_b\ (b_{ij}\ PM_i + DM_i) \tag{2.10}$$

where:

MM_{ij} = main memory acquisition cost (dollars) for system i using architecture j

b_{ij} = static storage ratio for architecture j and system i, derived from the architecture test results as described in the Appendix, Section 2.7

PM_i = main memory (in bits) required for program storage in system i; M_i is derived from system proponents; P is estimated fraction of M_i dedicated to program storage vs. data storage

DM_i = main memory (in bits) required for data storage in system i; M_i is derived from system proponents; D is estimated fraction of M_i dedicated to data storage vs. program storage

C_b = cost per bit of main memory derived from the study of Air Force ADP requirements through the 1980's [SADPR74] and Turn's data in his book, Computers in the 1980's [TurnR74]. Examination of the price per bit of recent militarized memory systems indicates an average cost of 4 cents per bit; i.e., $5000 per 16K byte memory module. This value is used in 1976 cost estimates; 0.4 cents is assumed in 1985 cost estimates.

(d) Secondary Memory Acquisition Cost

The secondary memory acquisition cost for system i using architecture j is defined as:

$$SM_{ij} = C_a (D_{ij} P'Ma_i + D'Ma_i) \qquad (2.11)$$

where:

SM_{ij} = secondary memory acquisition cost (dollars) for system i using architecture j

D_{ij} = static storage ratio for architecture j for system i, derived from the architecture test results as described in the Appendix, Section 2.7

$P'Ma_i$ = secondary memory (in bits) required for program storage in system i; Ma_i is derived from system proponents while P' is the estimated fraction of Ma_i used for program storage vs. data storage

$D'Ma_i$ = secondary memory (in bits) required for data storage in system i; Ma_i is derived from system proponents while D' is the estimated fraction of secondary memory used for data storage vs. program storage

C_a = cost per bit of secondary memory derived from the study of Air Force ADP requirements through the 1980's [SADPR74] and Turn's data [TurnR74].

Examination of the price per bit of current militarized disc systems indicates an average cost of 0.2 cents per bit, e.g.; a 36M bit disc system at $72,000. This value is used in 1976 cost estimates; a cost reduction of 10:1 in the next 10 years is assumed so that a price of 0.02 cents per bit is used in 1985 cost estimates.

(4) Applications Software Life Cycle Cost

The applications software life cycle cost for system i using architecture j is defined as:

$$ASw_{ij} = Cs_j \; S_i \; L_s \qquad (2.12)$$

where Cs_j = cost ($) per instruction of applications software for architecture j

S_i = applications software size (in instructions) for system i, derived from system proponents

L_s = applications software life cycle cost factor, i.e., ratio of applications software life cycle cost to initial acquisition cost

Ls, software life cycle cost factor, was taken basically from Fisher's report [FishD74, p.64] which places modifications and retrofits to software at four to five times the cost of the initial product. Thus by taking the midpoint and adding the initial cost as one, we have a value of Ls = 5.5.

Cs_j, cost per instruction of application software for architecture j, is based on the experience of System Development Corporation with five large scale (24K instructions to 500K instructions) software efforts. The data was compiled by sending questionnaires to the program managers. Program managers responded with: the cost of software production, the number of instructions produced, and for thirteen software tools they estimated what would be the percent increase in project cost if the tool were not available and how much less the project cost would be if the ideal tool were available. From generalizations of this data, it was possible to construct the curves shown in Figure 2-1.

These curves show the variation of cost per instruction as a function of the Tool Availability Index (TAI) for three conditions; (A) worst case, (B) best case and (C) derived median. It should be recognized that the results are largely judgmental and that examples can also be found which yield costs per instruction above and below the worst and best case curves of Figure 2-1. The Tool Availability Index (TAI) is defined as the ratio of available software tools to the ideal set of software tools. The "ideal set" is defined in a separate report by the Software Evaluation Methodology Subcommittee [WagnJ76].

By knowing the TAI for a given architecture for any point in time, one can enter Figure 2-1 and obtain an estimated cost per instruction. As the percentage of available software tools increases the cost per instruction of application software can be seen to diminish. The 1976 TAI for each CFA finalist was derived from the report of the Software Evaluation Committee [WagnJ76] as 34%, 50% and 73% for the Interdata 8/32, DEC PDP-11 and IBM S/370 architectures, respectively.* The average of these values is 52% and is indicated graphically in Figure 2-1. The cost per instruction for the average TAI is approximately $25, $10 and $17 for conditions A, B and C, respectively.

*A subsequent refinement of the data in the SEC report changes these percentages to 37%, 54% and 77%. The changes proved to have no significant impact on the data presented herein.

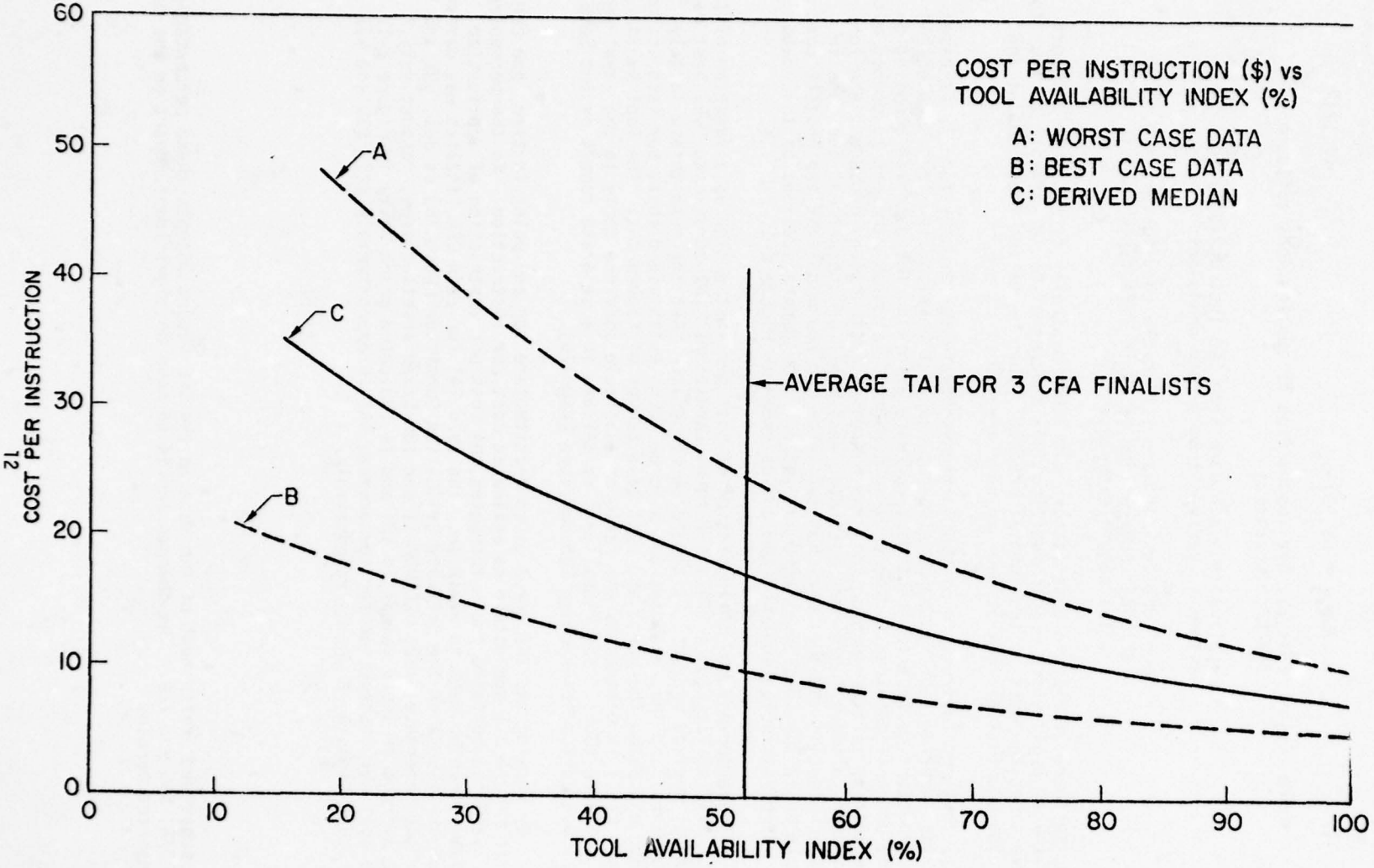
COST PER INSTRUCTION ($) vs
TOOL AVAILABILITY INDEX (%)
A: WORST CASE DATA
B: BEST CASE DATA
C: DERIVED MEDIAN
AVERAGE TAI FOR 3 CFA FINALISTS
A
B
C
COST PER INSTRUCTION
TOOL AVAILABILITY INDEX (%)
0
10
20
30
40
50
60
70
80
90
100

Figure 2-1

d. RESULTS

(1) System Proponent Data

To obtain values of n_i, Mr_i, M_i, Ma_i, and S_i, a letter was sent from ECOM to fifteen project managers requesting values for their particular system. The responses are tabulated in Table 2-2 . This table indicates that:

(a) The number of installations required (n_i) ranges from 8 to 3325 per system for a total of 6277 computers for all 15 systems.

(b) MIPS required ranges from .02 for System #12 (Large Data Management) to 1.33 for System #1 (Medium Search).

(c) Estimated main memory used for programs (PM_i) ranges from .006 to 13.6 Mbits. The average value of PM_i is 2.3 Mbits or approximately 288K bytes per system.

(d) The number of applications software instructions (S_i) varies from 1000 to 375,000 per system. The average value of S_i is 106,000 instructions.

(2) Processor Life Cycle Cost

The parametric data required for processor life cycle cost computations is shown in Table 2-3a. The processor speed ratio (a_{ij}) is computed in the Appendix, Section 2.7, from the architecture test results. The total processor life cycle cost for each system was computed as described in paragraph 2.3.3.2 and is shown in Table 2-3b for 1976 and 1985 procurements. The unit processor life cycle cost for each system is shown in Table 2-3c. The average unit processor life cycle cost for all systems and architectures is $86,400 in 1976.

The average unit processor life cycle costs of the DEC PDP-11 and Interdata 8/32 architectures are 8.2% and 6.4% below the average; the cost for IBM S/370 architecture is 14.5% above the average.

(3) Main Memory Life Cycle Cost

The parametric data required for main memory life cycle cost computation is shown in Table 2-4a. The static storage ratio (b_j) is computed in the Appendix, Section 2.7, from the architecture test results. The total main memory life cycle cost for each system was computed as described in paragraph 2.3.3.3 and is shown in Table 2-4b for 1976 and 1985 procurements. The unit main memory life cycle cost for each system is shown in Table 2-4c. The average unit main memory life cycle cost in 1976 for all systems and all architectures is $232,500. The costs using the PDP-11 and 8/32 architectures are 13.9% and 12.7% below the average while the cost using the IBM S/370 is 26.6% above the average.

Table 2-2

System Proponent Data

Sys. #	System Mission	n_i	Mr_i (MIPS)	*PM_i	*DM_i	*PMa_i	*DMa_i	S_i**
1	Medium Search	192	1.33	.414	.101	1.9	7.7	32
2	Medium Command and Control	27	.26	1.638	.412	2.2	8.8	144
3	Small Search	100	1.00	.512	.128	2.8	11.2	20
4	Large Command and Control	178	.20	13.600	3.400	4.0	16.0	375
5	Medium Command and Control	64	.50	1.600	.400	15.8	63.2	47
6	Large Command and Control	30	.40	3.321	.820	8.4	33.6	250
7	Small Command and Control	832	.75	.618	.152	.4	1.6	100
8	Large Communications	616	.18	3.200	.800	13.4	52.0	175
9	Small Communications	800	.16	.116	.031	0	0	8
10	Small Communications	9	.53	.408	.102	3.2	12.8	83
11	Small Special Purpose	30	.48	.328	.082	.1	.3	14
12	Large Data Management	16	.02	1.600	.400	573.4	2293.6	324
13	Medium Search	50	.35	3.712	.928	3.2	12.8	28
14	Medium Data Management	8	.80	3.200	.800	1912.0	7648.0	1
15	Small Guidance and Control	3325	.20	.006	.002	0	0	1

* P and D are fractions applied to the proponent's stated memory requirements which reflect an estimate of memory used for programs (P) vs. data (D). Values are expressed in megabits.

** S_i stated in 10^3 instructions.

Table 2-3a

Processor Life Cycle Cost Parameters

System #	System Mission	# Units n_i	Mr_i (MIPS)	Processor Speed Ratio, a_j INTERDATA	DEC PDP11	IBM S370
1	Medium Search	192	1.33	0.81	0.92	1.28
2	Medium Command and Control	27	.26	0.81	0.81	1.39
3	Small Search	100	1.00	0.84	0.78	1.28
4	Large Command and Control	178	.20	0.79	0.78	1.44
5	Medium Command and Control	64	.50	0.81	0.78	1.41
6	Large Command and Control	30	.40	0.79	0.83	1.38
7	Small Command and Control	832	.75	0.77	0.77	1.47
8	Large Communications	616	.18	0.81	0.75	1.46
9	Small Communications	800	.16	0.89	0.83	1.29
10	Small Communications	9	.53	0.87	0.79	1.35
11	Small Special Purpose	30	.48	0.78	0.73	1.49
12	Large Data Management	16	.02	0.80	0.85	1.36
13	Medium Search	50	.35	0.89	0.83	1.28
14	Medium Data Management	8	.80	0.83	0.77	1.41
15	Small Guidance and Control	3325	.20	0.80	0.76	1.42

Table 2-3b

Total Processor Life Cycle Cost vs. CFA for 1976 and 1985 Procurements

($ x 10^6)

Sys. #	SYSTEM MISSION	1976 Procurement			1985 Procurement		
		INTER-DATA 8/32	DEC PDP-11	IBM S370	INTER-DATA 8/32	DEC PDP-11	IBM S370
1	Medium Search	24.9	26.2	29.9	2.49	2.62	2.99
2	Medium Command and Control	1.8	1.8	2.3	.18	.18	.23
3	Small Search	11.8	11.4	13.9	1.18	1.14	1.39
4	Large Command and Control	10.7	10.7	13.6	1.07	1.07	1.36
5	Medium Command and Control	5.6	5.5	7.0	.56	.55	.70
6	Large Command and Control	2.4	2.4	3.0	.24	.24	.30
7	Small Command and Control	84.2	84.2	109.0	8.42	8.42	10.90
8	Large Communications	35.9	34.8	45.5	3.59	3.48	4.55
9	Small Communications	46.2	44.9	53.6	4.62	4.49	5.36
10	Small Communications	.8	.8	1.0	.08	.08	.10
11	Small Special Purpose	2.6	2.5	3.3	.26	.25	.33
12	Large Data Management	.4	.4	.5	.04	.04	.05
13	Medium Search	4.0	3.8	4.6	.40	.38	.46
14	Medium Data Management	.9	.8	1.0	.09	.08	.10
15	Small Guidance and Control	201.3	197.2	253.2	20.13	19.72	25.32

Table 2-3c

Unit Processor Life Cycle Cost vs CFA
for
1976 and 1985 Procurements

SYS. #	SYSTEM MISSION	# UNIT n_i	UNIT COST ($K) 1976 Procurement			1985 Procurement		
			8/32	PDP-11	S/370	8/32	PDP-11	S/370
1	Medium Search	192	129.7	1365	155.7	13.0	13.6	15.6
2	Medium Command and Control	27	66.7	66.7	85.2	6.7	6.7	8.5
3	Small Search	100	118.0	114.0	139.0	11.8	11.4	13.9
4	Large Command and Control	178	60.1	60.1	76.4	6.0	6.0	7.6
5	Medium Command and Control	64	87.5	85.9	109.4	8.8	8.6	10.9
6	Large Command and Control	30	80.0	80.0	100.0	8.0	8.0	10.0
7	Small Command and Control	832	101.2	101.2	131.0	10.1	10.1	13.1
8	Large Communications	616	58.3	56.5	73.9	5.8	5.6	7.4
9	Small Communications	800	57.8	56.1	67.0	5.8	5.6	6.7
10	Small Communications	9	88.9	88.9	111.1	8.9	8.9	11.1
11	Small Special Purpose	30	86.7	83.3	110.0	8.7	8.3	11.0
12	Large Data Management	16	25.0	25.0	31.2	2.5	2.5	3.1
13	Medium Search	50	80.0	76.0	92.0	8.0	7.6	9.2
14	Medium Data Management	8	112.5	100.0	125.0	11.2	10.0	12.5
15	Small Guidance and Control	3325	60.5	59.3	76.2	6.0	5.9	7.6
	Total of Unit Costs		1212.9	1189.5	1483.1	121.3	119.0	148.3
	Average Unit Cost		80.9	79.3	98.9	8.1	7.9	9.9
	% Relative to Average		(6.4)	(8.2)	14.5			

Table 2-4a

Main Memory Life Cycle Cost Parameters

Sys. #	System Mission	# Units n_i	Program Memory PM_i*	Data Memory DM_i*	Static Storage Ratio, b_j INTER-DATA 8/32	DEC PDP-11	IBM S370
1	Medium Search	192	.414	.101	0.84	0.93	1.21
2	Medium Command and Control	27	1.638	.412	0.86	0.85	1.30
3	Small Search	100	.512	.128	0.88	0.83	1.28
4	Large Command and Control	178	13.600	3.400	0.81	0.81	1.38
5	Medium Command and Control	64	1.600	.400	0.85	0.82	1.32
6	Large Command and Control	30	3.321	.830	0.84	0.84	1.32
7	Small Command and Control	832	.618	.152	0.81	0.82	1.37
8	Large Communications	616	3.200	.800	0.84	0.80	1.37
9	Small Communications	800	.116	.031	0.95	0.86	1.19
10	Small Communications	9	.408	.102	0.90	0.82	1.29
11	Small Special Purpose	30	.328	.082	0.83	0.78	1.39
12	Large Data Management	16	1.600	.400	0.83	0.85	1.32
13	Medium Search	50	3.712	.928	0.92	0.88	1.21
14	Medium Data Management	8	3.200	.800	.84	0.79	1.37
15	Small Guidance and Control	3325	.006	.002	0.86	0.82	1.32

* Values in megabits

Table 2-4b

Total Main Memory Life Cycle Cost vs. CFA
for
1976 and 1985 Procurements

($ x 10^6)

Sys. #	SYSTEM MISSION	1976 Procurement			1985 Procurement		
		INTER-DATA 8/32	DEC PDP-11	IBM S370	INTER-DATA 8/32	DEC PDP-11	IBM S370
1	Medium Search	6.89	7.47	9.44	0.69	0.75	0.94
2	Medium Command and Control	3.93	3.90	5.49	0.39	0.39	0.55
3	Small Search	4.63	4.42	6.27	0.46	0.44	0.63
4	Large Command and Control	205.28	205.28	315.67	20.53	20.53	31.57
5	Medium Command and Control	9.01	8.77	12.86	0.90	0.88	1.29
6	Large Command and Control	8.69	8.69	12.51	0.87	0.87	1.25
7	Small Command and Control	43.44	43.85	66.47	4.34	4.39	6.65
8	Large Communications	171.89	165.58	255.47	17.19	16.56	25.55
9	Small Communications	9.04	8.37	10.82	0.90	0.84	1.08
10	Small Communications	0.34	0.31	0.45	0.03	0.03	0.46
11	Small Special Purpose	2.62	2.58	3.06	0.26	0.26	0.31
12	Large Data Management	2.21	2.25	3.22	0.22	0.26	0.32
13	Medium Search	17.37	16.78	21.68	1.74	1.68	2.17
14	Medium Data Management	2.23	2.13	3.32	0.22	0.21	0.33
15	Small Guidance and Control	1.90	1.84	2.64	0.19	0.18	0.26

Table 2-4c
Unit Main Memory Life Cycle Cost vs. CFA
for
1976 and 1985 Procurements

SYS. #	SYSTEM MISSION	# UNIT n_i	UNIT COST ($K) 1976 Procurement 8/32	PDP-11	S/370	1985 Procurement 8/32	PDP-11	S/370
1	Medium Search	192	35.9	38.9	49.2	3.6	3.9	4.9
2	Medium Command and Control	27	145.6	144.4	203.3	14.6	14.4	20.3
3	Small Search	100	46.3	44.2	62.7	4.6	4.4	6.3
4	Large Command and Control	178	1153.3	1153.3	1173.4	115.3	115.3	117.3
5	Medium Command and Control	64	140.8	137.0	200.9	14.1	13.7	20.1
6	Large Command and Control	30	289.7	289.7	417.0	29.0	29.0	41.7
7	Small Command and Control	832	52.2	52.7	79.9	5.2	5.3	8.0
8	Large Communications	616	279.0	268.8	414.7	27.9	26.9	41.5
9	Small Communications	800	11.3	10.5	13.5	1.1	1.0	1.4
10	Small Communications	9	37.8	34.4	50.0	3.8	3.4	5.0
11	Small Special Purpose	30	87.3	86.0	102.0	8.7	8.6	10.2
12	Large Data Management	16	138.1	140.6	201.2	13.8	14.1	20.1
13	Medium Search	50	347.4	335.6	433.6	34.7	33.6	43.4
14	Medium Data Management	8	278.8	266.2	415.0	27.9	26.6	41.5
15	Small Guidance and Control	3325	0.6	0.6	0.8	0.1	0.1	0.1
	Total of Unit Cost		3044.1	3022.9	4417.2	304.4	302.3	441.7
	Average Unit Cost		202.9	200.2	294.5	20.3	20.0	29.4
	% Relative to Average		(12.7)	(13.9)	26.6			

(4) Secondary Memory Life Cycle Cost

The parametric data required for secondary memory life cycle cost computation is shown in Table 2-5a. The total secondary memory life cycle cost for each system was computed as described in paragraph 2.3.3.4 and is shown in Table 2-5b. The unit secondary memory life cycle cost for each system is shown in Table 2-5c. The average unit secondary memory life cycle cost for all systems and architectures in 1976 is $3.4M. The costs using the PDP-11 and 8/32 architectures are 3.9% and 3.2% below the average while the cost using the IBM S/370 is 7.2% above the average.

(5) Total Hardware Life Cycle Cost

Tables 2-3b, 2-4b and 2-5b are summed to obtain the total hardware life cycle cost vs. CFA for 1976 and 1985 procurements. The result is shown in Table 2-6a. Table 2-6a indicates that the DEC PDP-11 and Interdata 8/32 architectures provide significantly lower hardware costs than the IBM S/370 architecture. The average hardware life cycle cost for all systems/architectures in 1976 is $1.75B. The costs using PDP-11 and 8/32 architectures are 8.7% and 7.7% below the average while the cost using the S/370 architecture is 16.4% above the average in 1976.

Tables 2-3c, 2-4c and 2-5c are summed to obtain the unit hardware life cycle cost vs. CFA for 1976 and 1985 procurements as shown in Table 2-6b. The average unit hardware life cycle cost for all systems/architectures in 1976 is $3.7M. The unit costs using the PDP-11 and 8/32 architectures are 4.7% and 3.9% below the average while the cost using the S/370 is 8.6% above the average in 1976.

(6) Applications Software Life Cycle Cost

To determine the applications software life cycle cost, it was necessary to derive the software tool availability index from the report of the Software Evaluation Methodology Subcommittee [WagnJ 76] for each CFA for 1976 and 1985; then, to compute the cost per applications software instruction.

As a baseline for the computation of the applications software life cycle cost in accordance with paragraph 2.3.3.5, the median cost curve shown in Figure 2-2 was employed. At the average TAI of 52%, this curve indicates a cost per instruction of $17, for 1976. The cost per instruction for the 3 CFA finalists in 1976 was estimated at $24, $18, and $12 for Interdata 8/32, DEC PDP-11 and IBM S/370, based upon TAI values of 34%, 50% and 73%, respectively. The corresponding values for 1985 were computed by assuming an annual expenditure of $2M to augment the support software base of the selected CFA. The resulting TAI values in 1985 are 83%, 100% and 100% corresponding to cost per instruction of $10, $7.50 and $7.50 for Interdata 8/32 DEC PDP-11 and IBM S/370, respectively. This data was then employed to compute applications software life cycle cost for each of the 15 systems under consideration, for each CFA and for 1976 and 1985. The resulting life cycle costs are shown in Table 2-7 assuming an annual support software expenditure of $2M. This table indicates that the average applications software life cycle cost in 1976 for all systems/architectures is $162M. The cost using the PDP-11 is approximately equal to the average while the costs using 8/32 and S/370 are 33% above and 33% below the average respectively in 1976.

In 1985, the average software life cycle cost is reduced to $75M. The cost using the PDP-11 and S/370 are 9.7% below the average while the cost using the 8/32 is 19% above the average in 1985.

Table 2-5a

Secondary Memory Life Cycle Cost Parameters

Sys. #	SYSTEM MISSION	# Units n_i	Program Memory PM_i *	Data Memory DM_i *	Static Storage Ratio, b_j INTER-DATA 8/32	DEC PDP-11	IBM S370
1	Medium Search	192	1.9	7.7	0.84	0.93	1.24
2	Medium Command and Control	27	2.2	8.8	0.86	0.85	1.30
3	Small Search	100	2.8	11.2	0.88	0.83	1.28
4	Large Command and Control	178	4.0	16.0	0.81	0.81	1.38
5	Medium Command and Control	64	15.8	63.2	0.85	0.82	1.32
6	Large Command and Control	30	8.4	33.6	0.84	0.84	1.32
7	Small Command and Control	832	.4	1.6	0.81	0.82	1.37
8	Large Communications	616	13.0	52.0	0.84	0.80	1.37
9	Small Communications	800	0	0	0.95	0.86	1.19
10	Small Communications	9	3.2	12.8	0.90	0.82	1.29
11	Small Special Purpose	30	.1	.3	0.83	0.78	1.39
12	Large Data Management	16	573.4	2293.6	0.83	0.85	1.32
13	Medium Search	50	3.2	12.8	0.92	0.88	1.21
14	Medium Data Management	8	1912.0	7648.0	0.84	0.79	1.37
15	Small Guidance and Control	3325	0	0	0.86	0.82	1.32

* Values in megabits

Table 2-5b

Total Secondary Memory Life Cycle Cost vs. CFA
for
1976 and 1985 Procurements

($ \times 10^6$)

Sys. #	SYSTEM MISSION	1976 Procurement			1985 Procurement		
		INTER-DATA 8/32	DEC PDP-11	IBM S370	INTER-DATA 8/32	DEC PDP-11	IBM S370
1	Medium Search	7.14	7.27	7.72	0.71	0.73	0.77
2	Medium Command and Control	1.15	1.15	1.26	0.11	0.11	0.13
3	Small Search	5.46	5.41	5.91	0.55	0.54	0.59
4	Large Command and Control	13.70	13.70	15.32	1.37	1.37	1.53
5	Medium Command and Control	19.61	19.50	21.52	1.96	1.95	2.15
6	Large Command and Control	4.88	4.88	5.86	0.49	0.49	0.59
7	Small Command and Control	6.40	6.41	7.65	0.64	0.64	0.76
8	Large Communications	155.03	153.75	172.01	15.50	15.37	17.20
9	Small Communications	0	0	0	0	0	0
10	Small Communications	.56	.55	.61	0.06	0.06	0.06
11	Small Special Purpose	.04	.04	.05	0	0	0
12	Large Data Management	177.25	177.98	195.23	17.72	17.80	19.52
13	Medium Search	3.15	3.12	3.38	0.31	0.31	0.34
14	Medium Data Management	296.13	293.07	328.56	29.61	29.61	32.86
15	Small Guidance and Control	0	0	0	0	0	0

Table 2-5c
Unit Secondary Memory Life Cycle Cost vs. CFA
for
1976 and 1985 Procurements

SYS. #	SYSTEM MISSION	# UNIT n_i	UNIT COST ($K) 1976 Procurement 8/32	PDP-11	S/370	1985 Procurement 8/32	PDP-11	S/370
1	Medium Search	192	37.2	37.9	40.2	3.7	3.8	4.0
2	Medium Command and Control	27	42.6	42.6	46.7	4.3	4.3	4.7
3	Small Search	100	54.6	54.1	59.1	5.5	5.4	5.9
4	Large Command and Control	178	77.0	77.0	86.1	7.7	7.7	8.6
5	Medium Command and Control	64	306.4	304.6	336.2	30.6	30.5	33.6
6	Large Command and Control	30	162.7	162.7	195.3	16.3	16.3	19.5
7	Small Command and Control	832	7.7	7.7	9.2	0.8	0.8	0.9
8	Large Communications	616	251.7	249.6	279.2	25.2	25.0	27.9
9	Small Communications	800	0	0	0	0	0	0
10	Small Communications	9	62.2	61.1	67.8	6.2	6.1	6.8
11	Small Special Purpose	30	1.3	1.3	1.7	0.1	0.1	0.2
12	Large Data Management	16	11078.1	11123.8	12201.9	1107.8	1112.4	1220.2
13	Medium Search	50	63.0	62.4	67.6	6.3	6.2	6.8
14	Medium Data Management	8	37016.2	36633.8	41070.0	3701.6	3663.4	4107.0
15	Small Guidance and Control	3325	0	0	0	0	0	0
	Total of Unit Cost		49160.7	48818.6	54461.0	4916.1	4881.9	5446.1
	Average Unit Cost		3277.4	3254.6	3630.7	327.7	325.5	363.1
	% Relative to Average		(3.2)	(3.9)	7.2			

Table 2-6a

Total Hardware Life Cycle Cost vs. CFA
for
1976 and 1985 Procurements

($ x 10^6)

Sys. #	SYSTEM MISSION	1976 Procurement			1985 Procurement		
		INTER-DATA 8/32	DEC PDP-11	IBM S370	INTER-DATA 8/32	DEC PDP-11	IBM S370
1	Medium Search	38.9	40.9	47.1	3.9	4.1	4.7
2	Medium Command and Control	6.9	6.9	9.1	0.7	0.7	0.9
3	Small Search	21.9	21.2	26.1	2.2	2.1	2.6
4	Large Command and Control	229.7	229.7	344.60	23.0	23.0	34.5
5	Medium Command and Control	34.2	33.8	41.4	3.4	3.4	4.1
6	Large Command and Control	16.0	16.0	21.4	1.6	1.6	2.1
7	Small Command and Control	134.0	134.5	183.1	13.4	13.4	18.3
8	Large Communications	362.8	354.1	473.0	36.3	35.4	47.3
9	Small Communications	55.2	53.3	64.4	5.5	5.3	6.4
10	Small Communications	1.7	1.7	2.1	.2	.2	.2
11	Small Special Purpose	5.3	5.1	6.4	.5	.5	.6
12	Large Data Management	179.9	180.6	199.0	18.0	18.1	19.9
13	Medium Search	24.5	23.7	29.7	2.4	2.4	3.0
14	Medium Data Management	299.3	296.0	332.9	29.9	29.6	33.3
15	Small Guidance and Control	203.2	199.0	255.8	20.3	19.9	25.6
	Total Cost	1614	1597	2036	161.3	159.7	203.5
	% Relative to Average	(7.7)	(8.7)	16.4			

Table 2-6b
Unit Hardware Life Cycle Cost vs. CFA
for
1976 and 1985 Procurements

SYS. #	SYSTEM MISSION	# UNIT n_i	UNIT COST ($K) 1976 Procurement			1985 Procurement		
			8/32	PDP-11	S/370	8/32	PDP-11	S/370
1	Medium Search	192	202.8	213.5	245.1	20.3	21.3	24.5
2	Medium Command and Control	27	254.9	253.7	335.2	25.5	25.4	33.5
3	Small Search	100	218.9	212.3	260.8	21.9	21.2	26.1
4	Large Command and Control	178	1290.4	1290.4	1936.0	129.0	129.0	193.6
5	Medium Command and Control	64	534.4	528.1	646.9	53.4	52.8	64.7
6	Large Command and Control	30	533.3	533.3	713.3	53.3	53.3	71.3
7	Small Command and Control	832	161.7	161.7	220.1	16.1	16.2	22.0
8	Large Communications	616	589.0	574.8	767.9	58.9	57.5	76.8
9	Small Communications	800	69.0	66.6	80.5	6.9	6.7	8.0
10	Small Communications	9	188.9	188.9	233.3	18.9	18.9	23.3
11	Small Special Purpose	30	176.7	170.0	213.3	17.7	17.0	21.3
12	Large Data Management	16	11243.8	11287.5	12437.5	1124.4	1128.8	1143.8
13	Medium Search	50	490.0	474.0	594.0	49.0	47.4	59.4
14	Medium Data Management	8	37412.5	37000.0	41612.5	3741.2	3700.0	4161.2
15	Small Guidance and Control	3325	61.1	59.8	76.9	6.1	6.1	7.7
	Total of Unit Costs		53427	53014	60373	5343	5301	6037
	Average Unit Cost		3562	3534	4025	356	353	402
	% Relative to Average		(3.9)	(4.7)	8.6			

Table 2-7

Applications Software Life Cycle Cost vs. CFA
Assuming Software Tool Expenditure of $2M/Yr

($ x 10^6)

SYS. #	SYSTEM MISSION	1976 Procurement			1985 Procurement		
		INTER-DATA 8/32	DEC PDP-11	IBM S370	INTER-DATA 8/32	DEC PDP-11	IBM S370
1	Medium Search	4.22	3.17	2.11	1.76	1.32	1.32
2	Medium Command and Control	19.01	14.26	9.50	7.92	5.94	5.94
3	Small Search	2.64	1.98	1.32	1.10	.83	.83
4	Large Command and Control	49.50	37.13	24.75	20.63	15.47	15.47
5	Medium Command and Control	6.20	4.65	3.10	2.59	1.94	1.94
6	Large Command and Control	33.00	24.75	16.50	13.75	10.31	10.31
7	Small Command and Control	13.20	9.90	6.60	5.50	4.13	4.13
8	Large Communications	23.10	17.33	11.55	9.63	7.33	7.22
9	Small Communications	1.06	.79	.53	.44	.33	.33
10	Small Communications	10.96	8.22	5.48	4.57	3.42	3.42
11	Small Special Purpose	1.85	1.39	.92	.77	.58	.58
12	Large Data Management	42.77	32.08	21.38	17.82	13.37	13.37
13	Medium Search	3.70	2.77	1.85	1.54	1.16	1.16
14	Medium Data Management	4.62	3.47	2.31	1.92	1.44	1.44
15	Small Guidance and Control	.13	.10	.07	.06	.04	.04
	Total Cost	216	162	108	90	68	68
	% Relative to Average	33	-	(33)	19	(9.7)	(9.7)

(7) Total Life Cycle Cost vs. CFA

Table 2-8a displays, in a single chart, the comparison of total life cycle costs for each of the three architectures for 1976. Table 2-8b presents the same information for 1985. Circled values indicate the least cost architecture for a particular system and the least total cost for implementing all fifteen systems. The number of times an architecture is thus selected is also totaled and shown at the bottom of the chart as the Number of System Preferences. Table 2-8a indicates that:

(a.) In 1976, the DEC PDP-11, IBM S/370 and Interdata 8/32 would have been selected for 11, 3 and 1 systems, respectively, on a life cycle cost basis. The average total life cycle cost for all systems/architectures in 1976 is $1.91B. The PDP-11 and 8/32 costs are comparable being 8.0% and 4.2%, respectively below the average. The S/370 cost is 12.2% above the average or 20.2% above the PDP-11 cost.

(b.) In 1985, (Table 2-8b) the system preferences for DEC, IBM and Interdata would be 14.5, 0.5 and none, respectively. The average total life cycle cost for all systems/architectures is $250M in 1985. The 8/32 cost is approximately equal to the average cost while the PDP-11 and S/370 costs are 8.9% below and 8.7% above, respectively, the average cost.

(8) Sensitivity Analysis

The results shown in Tables 2-8a and 2-8b are based upon the following parametric values:

(a.) Cost per Instruction. The use of the median curve in Figure 2-2 for estimating the cost per applications software instruction as a function of TAI. This curve yields an average cost per instruction of $17 in 1976 for the three CFA finalists. This value corresponds to an average hardware:software life cycle cost ratio of 12:1 and 2.4:1 in 1976 and 1985, respectively, as shown in Table 2-9.

(b.) Support Software Investment Rate. The data presented thus far reflects the use of $2M per year to augment the support software base. Table 2-10 indicates the impact of alternate investment rates of $1M and $3M annually upon the 1985 cost per instruction.

(c.) Weighted S, M and R Values. The architecture measures of effectiveness (S, M and R) are weighted for each system application as described in the Appendix, Section 2.7.

The above parametric values were perturbed in order to determine the sensitivity of the life cycle cost model. The results are described in the following subparagraphs.

(9) Instruction Cost Sensitivity

The average cost per instruction in 1976 was doubled to $34, or $9 in excess of the worst-case curve in Figure 2-1. The resulting hardware:software ratios are 6:1 and 1.2:1 in 1976 and 1985 respectively, as shown in Table 2-9. The resulting life cycle costs for 1976 and 1985 are depicted in Tables 2-11a and 2-11b, respectively. These tables indicate that in terms of the comparative costs of the three architectures, the model is relatively insensitive to doubling the cost per applications software instruction. Comparing Tables 2-8a and 2-11a, IBM is shown to pick up one system implementation at both DEC and Interdata expense in 1976 so that DEC, IBM and Interdata architectures would be preferred in 10.5, 4.0 and 0.5 systems, respectively. The DEC architecture remains the lowest in total life cycle cost for all systems. For 1985, comparing Tables 2-8b and 2-11b shows no change with DEC architecture being preferred in 14.5 systems.

(10) Support-Software Investment-Rate Sensitivity

The data examined thus far for 1985 reflect an investment in the software bases of the three architectures of $2M annually.

The data for 1985 were re-examined to determine the impact of reducing the investment in the software base to $1M annually for two different situations, i.e., for the basic cost per instruction of application software and then double the basic cost. The data are summarized in Tables 2-12a and 2-12b, respectively. Table 2-12a shows that the selection of IBM would increase to 5 systems while DEC would drop to 10. This is also predictable since at a $1M per year investment rate in the software base IBM retains for a longer time its cost advantage in producing application software. At this lower investment rate, Table 2-10 shows that while IBM has achieved the ideal support software set, DEC has only 63% while Interdata has 61%.

Doubling the cost per application software instruction merely extends a software favorable situation as shown in Table 2-12b. In this table, IBM selections equal DEC selections at seven.

(11) Sensitivity to Unweighted S, M, and R Values

The data presented in the report uses weighted values of the S, M, and R data resulting from test program runs and provided by Carnegie Mellon University. The weights and the calculations are discussed in some detail in the Appendix, Section 2.7.

The data was re-examined to determine the impact if the S, M, and R measures were used without the discriminating weights applied. The results are displayed in Table 2-13 and show that, for 1985, the model is relatively insensitive to the weighting factors applied to the S, M, and R values. At $17 per application software instruction a few systems shift from DEC to Interdata; at $34 per instruction a few systems shift from DEC to IBM. DEC remains predominant. However, for 1975, the Interdata gains the low-cost position for unweighted S, M, & R.

(12) Summary of Perturbations

In subparagraphs 2.4.9 to 2.4.11, we have re-examined the bottom up model to determine its sensitivity to several key parameters. The results are summarized in Table 2-14 which shows the impact on the number of times an architecture would be selected to implement the fifteen Army systems for each of the

TABLE 2-8a

Total Life Cycle Cost vs CFA

1976 Procurement

1976 AVERAGE APPL'N SW COST = $17/INSTRUCTION

SYS #	SYSTEM MISSION	n_i	INTERDATA 8/32			DEC PDP-11			IBM S370		
			HDW	ASW	TOTAL	HDW	ASW	TOTAL	HDW	ASW	TOTAL
1	Medium Search	192	38.9	4.2	43.1	40.9	3.2	44.1	47.1	2.1	49.2
2	Medium Command and Control	27	6.9	19.0	25.9	6.9	14.3	21.2	9.1	9.5	18.6
3	Small Search	100	21.9	2.6	24.5	21.2	2.0	23.2	26.1	1.3	29.4
4	Large Command and Control	178	230.0	49.5	280.0	229.0	37.1	267.0	345.0	24.8	369.0
5	Medium Command and Control	64	34.2	6.2	40.4	33.8	4.7	38.5	41.4	3.1	44.5
6	Large Command and Control	30	16.0	33.0	49.0	16.0	24.8	40.8	21.4	16.5	37.9
7	Small Command and Control	832	134.0	13.2	147.0	135.0	9.9	144.0	183.0	6.6	190.0
8	Large Communications	616	363.0	23.1	386.0	354.0	17.3	371.0	473.0	11.6	485.0
9	Small Communications	800	55.2	1.1	56.3	53.3	0.8	54.1	64.4	0.5	64.9
10	Small Communications	9	1.7	11.0	12.7	1.7	8.2	9.9	2.1	5.5	7.6
11	Small Special Purpose	30	5.3	1.9	7.1	5.1	1.4	6.5	6.4	0.9	7.3
12	Large Data Management	16	180.0	42.8	223.0	181.0	32.0	213.0	199.0	21.4	220.0
13	Medium Search	50	24.5	3.7	28.2	23.7	2.8	26.5	29.7	1.9	31.5
14	Medium Data Management	8	299.0	4.6	304.0	296.0	3.5	300.0	333.0	2.3	335.0
15	Small Guidance and Control	3325	203.0	0.1	203.0	199.0	0.1	199.0	256.0	0.1	256.0
	Total Cost		1614	216	1830	1596	162	1758	2037	108	2145
	# System Preferences				1.0			11			3.0

TABLE 2-8b

Total Life Cycle Cost vs CFA

1985 Procurement and Software Tool Expenditure of $2M/yr

1976 Average Appl'n SW Cost = $17/Instruction

SYS #	SYSTEM MISSION	n_i	INTERDATA 8/32			DEC PDP-11			IBM S370		
			HDW	ASW	TOTAL	HDW	ASW	TOTAL	HDW	ASW	TOTAL
1	Medium Search	192	3.9	1.8	5.7	4.1	1.3	5.4	4.7	1.3	6.0
2	Medium Command and Control	27	0.7	7.9	8.6	0.7	5.9	6.6	0.9	5.9	6.8
3	Small Search	100	2.2	1.1	3.3	2.1	0.8	2.9	2.6	0.8	3.4
4	Large Command and Control	178	23.0	20.6	43.6	23.0	15.5	38.5	34.5	15.5	50.0
5	Medium Command and Control	64	3.4	2.6	6.0	3.4	1.9	5.3	4.1	1.9	6.0
6	Large Command and Control	30	1.6	13.8	15.4	1.6	10.3	11.9	2.1	10.3	12.4
7	Small Command and Control	832	13.4	5.5	18.9	13.4	4.1	17.5	18.3	4.1	22.4
8	Large Communications	616	36.3	9.6	45.9	35.4	7.3	42.7	47.3	7.2	54.5
9	Small Communications	800	5.5	0.4	5.9	5.3	0.3	5.6	6.4	0.3	6.7
10	Small Communications	9	0.2	4.6	4.8	0.2	3.4	3.6	0.2	3.4	3.6
11	Small Special Purpose	30	0.5	0.8	1.3	12.5	0.6	1.1	0.6	0.6	1.2
12	Large Data Management	16	18.0	17.8	35.8	18.1	13.4	31.5	19.9	13.4	33.3
13	Medium Search	50	2.4	1.5	3.9	2.4	1.2	3.6	3.0	1.2	4.2
14	Medium Data Management	8	29.9	1.9	31.8	29.6	1.4	31.0	33.3	1.4	34.7
15	Small Guidance and Control	3325	20.3	0.1	20.4	19.9	0.1	20.0	25.6	0.1	25.7
	Total Cost		161	90	251	160	68	228	204	68	272
	# System Preferences				-			14.5			0.5

Table 2-9

Hardware:Software Ratios

BOTTOM-UP LIFE CYCLE COST MODEL

CFA	1976 AVG APPL'N SW COST = $17/I		1976 AVG APPL'N SW COST = $34/I	
	1976 PROC.	1985 PROC.	1976 PROC.	1985 PROC.
INTERDATA 8/32	7.5	1.8	3.7	0.9
DEC PDP-11	9.8	2.4	4.9	1.2
IBM S370	18.9	3.0	9.4	1.5
AVERAGE	12	2.4	6.0	1.2

Table 2-10

Application Software Cost Per Instruction
vs
Support Software Investment Rate

A. Software Tool Availability Index

Annual Support Software Investment $M	1976 INTERDATA 8/32	1976 DEC PDP-11	1976 IBM S370	1985 INTERDATA 8/32	1985 DEC PDP-11	1985 IBM S370
1	.34	.50	.73	0.61	0.83	1.0
2	.34	.50	.73	0.83	1.0	1.0
3	.34	.50	.73	1.0	1.0	1.0

B. Applications Software Cost Per Instruction ($)

1	24.00	18.00	12.00	14.00	10.00	7.50
2	24.00	18.00	12.00	10.00	7.50	7.50
3	24.00	18.00	12.00	7.50	7.50	7.50

TABLE 2-11a

Total Life Cycle Cost vs CFA

1976 Procurement

1976 AVERAGE APPL'N SW COST = $34/INSTRUCTION

SYS #	SYSTEM MISSION	n_i	INTERDATA 8/32			DEC PDP-11			IBM S370		
			HDW	ASW	TOTAL	HDW	ASW	TOTAL	HDW	ASW	TOTAL
1	Medium Search	192	38.9	8.4	47.3	40.9	6.4	47.3	47.1	4.2	51.3
2	Medium Command and Control	27	6.9	38.0	44.9	6.9	28.6	35.5	9.1	19.0	28.1
3	Small Search	100	21.9	5.2	27.1	21.2	4.0	25.2	26.1	2.6	20.7
4	Large Command and Control	178	230.0	99.0	330.0	229.0	74.2	304.0	345.0	49.6	394.0
5	Medium Command and Control	64	34.2	12.4	46.6	33.8	9.4	43.2	41.4	6.2	47.6
6	Large Command and Control	30	16.0	66.0	82.0	16.0	49.6	65.6	21.4	33.0	54.4
7	Small Command and Control	832	134.0	26.4	160.0	135.0	19.8	154.0	183.0	13.2	197.0
8	Large Communications	616	363.0	46.2	409.0	354.0	34.6	388.0	473.0	23.2	497.0
9	Small Communications	800	55.2	2.2	57.4	53.3	1.6	54.9	64.4	1.0	65.4
10	Small Communications	9	1.7	22.0	23.7	1.7	16.4	18.1	2.1	11.0	13.1
11	Small Special Purpose	30	5.3	3.8	9.0	5.1	2.8	7.9	6.4	1.8	8.2
12	Large Data Management	16	180.0	85.6	266.0	181.0	64.0	245.0	199.0	42.8	241.0
13	Medium Search	50	24.5	7.4	31.9	23.7	5.6	29.3	29.7	3.8	33.4
14	Medium Data Management	8	299.0	9.2	309.0	296.0	7.0	304.0	333.0	4.6	337.0
15	Small Guidance and Control	3325	203.0	0.2	203.0	199.0	0.2	199.0	256.0	0.2	256.0
	Total Cost		1614	432	2046	1596	324	1920	2037	216	2253
	# System Preferences				0.5			10.5			4.0

TABLE 2-11b

Total Life Cycle Cost vs CFA

1985 Procurement / $2M yr Support SW Expenditure

1976 Average Appl'n SW Cost = $34/Instruction

SYS #	SYSTEM MISSION	n_i	INTERDATA 8/32			DEC PDP-11			IBM S370		
			HDW	ASW	TOTAL	HDW	ASW	TOTAL	HDW	ASW	TOTAL
1	Medium Search	192	3.9	3.6	7.5	4.1	2.6	6.7	4.7	2.6	7.3
2	Medium Command and Control	27	0.7	15.8	16.5	0.7	11.8	12.5	0.9	11.8	12.7
3	Small Search	100	2.2	2.2	4.4	2.1	1.6	3.7	2.6	1.6	4.2
4	Large Command and Control	178	23.0	41.2	64.2	23.0	31.0	54.0	34.5	31.0	65.5
5	Medium Command and Control	64	3.4	5.2	8.6	3.4	3.8	7.2	4.1	3.8	7.9
6	Large Command and Control	30	1.6	27.6	29.2	1.6	20.6	22.2	2.1	20.6	22.7
7	Small Command and Control	832	13.4	11.0	24.4	13.4	8.2	21.6	18.3	8.2	26.5
8	Large Communications	616	36.3	19.2	55.5	35.4	14.6	50.0	47.3	14.6	61.7
9	Small Communications	800	5.5	0.8	6.3	5.3	0.6	5.9	6.4	0.6	7.0
10	Small Communications	9	0.2	9.2	9.4	0.2	6.8	7.0	0.2	6.8	7.0
11	Small Special Purpose	30	0.5	1.6	2.1	0.5	1.2	1.7	0.6	1.2	1.8
12	Large Data Management	16	18.0	35.6	53.6	18.1	26.8	44.9	19.9	26.8	46.7
13	Medium Search	50	2.4	3.0	5.4	2.4	2.4	4.8	3.0	2.4	5.4
14	Medium Data Management	8	29.9	3.8	33.7	29.6	2.8	32.4	33.3	2.8	36.1
15	Small Guidance and Control	3325	20.3	0.2	20.5	19.9	0.2	20.1	25.6	0.2	25.8
	Total Cost		161	180	341	160	136	2966	204	136	340
	# System Preferences				-			14.5			0.5

TABLE 2-12a

Total Life Cycle Cost vs CFA ($ x 10^6)

1985 Procurement and Software Tool Expenditure of $1M/yr

1976 Average Appl'n SW Cost = $17/Instruction

SYS #	SYSTEM MISSION	n_i	INTERDATA 8/32			DEC PDP-11			IBM S370		
			HDW	ASW	TOTAL	HDW	ASW	TOTAL	HDW	ASW	TOTAL
1	Medium Search	192	3.9	2.5	6.4	4.1	1.8	5.9	4.7	1.3	6.0
2	Medium Command and Control	27	0.7	11.1	11.8	0.7	7.9	8.6	0.9	5.3	6.8
3	Small Search	100	2.2	1.5	3.7	2.1	1.1	3.2	2.6	0.8	3.4
4	Large Command and Control	178	23.0	28.9	51.9	23.0	20.6	43.6	34.5	15.5	50.0
5	Medium Command and Control	64	3.4	3.6	7.0	3.4	2.6	6.0	4.1	1.9	6.0
6	Large Command and Control	30	1.6	19.3	20.9	1.6	13.8	15.4	2.1	10.3	12.4
7	Small Command and Control	832	13.4	7.7	21.1	13.4	5.5	18.9	18.3	4.1	22.4
8	Large Communications	616	36.3	13.5	49.8	35.4	9.6	45.0	47.3	7.2	54.5
9	Small Communications	800	5.5	0.6	6.1	5.3	0.4	5.7	6.4	0.3	6.7
10	Small Communications	9	0.2	1.4	6.6	0.2	4.6	4.8	0.2	3.4	3.6
11	Small Special Purpose	30	0.5	1.1	1.6	0.5	0.7	1.2	0.6	0.6	1.2
12	Large Data Management	16	18.0	24.9	42.9	18.1	17.8	35.9	19.9	13.4	33.3
13	Medium Search	50	2.4	2.2	4.6	2.4	1.4	3.9	3.0	1.2	4.2
14	Medium Data Management	8	29.9	2.5	32.6	29.6	1.9	31.5	33.3	1.4	34.7
15	Small Guidance and Control	3325	20.3	0.1	20.4	19.9	0.1	20.0	25.6	0.1	25.7
	Total Cost		161	121	282	160	90	250	204	68	272
	# System Preferences				0			10			5

TABLE 2-12b

Total Life Cycle Cost vs CFA ($ x 10^6)

1985 Procurement and Software Tool Expenditure of $1M/yr

1976 Average Appl'n SW Cost = $34/Instruction

SYS #	SYSTEM MISSION	n_i	INTERDATA 8/32			DEC PDP-11			IBM S370		
			HDW	ASW	TOTAL	HDW	ASW	TOTAL	HDW	ASW	TOTAL
1	Medium Search	192	3.9	5.0	8.9	4.1	3.6	7.7	4.7	2.6	7.3
2	Medium Command and Control	27	0.7	22.2	22.9	0.7	15.8	16.5	0.9	11.8	12.7
3	Small Search	100	2.2	3.0	5.2	2.1	2.2	4.3	2.6	1.6	4.2
4	Large Command and Control	178	23.0	57.8	80.8	23.0	41.2	64.2	34.5	31.0	65.5
5	Medium Command and Control	64	3.4	7.2	10.6	3.4	5.2	8.6	4.1	3.8	7.9
6	Large Command and Control	30	1.6	38.6	40.2	1.6	27.6	29.2	2.1	20.6	22.7
7	Small Command and Control	832	15.4	15.4	26.8	13.4	11.0	24.4	18.3	8.2	26.5
8	Large Communications	616	36.3	27.0	63.3	35.4	19.2	54.6	47.3	14.4	61.7
9	Small Communications	800	5.5	1.2	6.7	5.3	0.8	6.1	6.4	0.6	7.0
10	Small Communications	9	0.2	2.8	3.0	0.2	9.2	9.4	0.2	6.8	7.0
11	Small Special Purpose	30	0.5	2.2	2.7	0.5	1.4	1.9	0.6	1.2	1.8
12	Large Data Management	16	18.0	49.8	67.8	18.1	35.6	53.7	19.9	26.8	46.7
13	Medium Search	50	2.4	4.4	6.8	2.4	2.8	5.2	3.0	2.4	5.4
14	Medium Data Management	8	29.9	5.0	34.0	29.6	3.8	33.4	33.3	2.8	36.1
15	Small Guidance and Control	3325	20.3	0.2	20.5	19.9	0.2	20.1	25.6	0.2	25.8
	Total Cost		161	242	403	160	180	340	204	136	340
	# System Preferences				1			7			7

TABLE 2-14

Summary: Architecture Selection
vs
Cost Model Parameters

Case No.	ARCHITECTURE			PROCUREMENT YEAR		ANNUAL SW BASE INVESTMENT			AVG. COST PER INSTR. ASW		
	IBM	DEC	INT	1976	1985	$1M	$2M	$3M	$15	$30	Unweighted S, M, R
1	3	11	1	X					X		
2	0.5	14.5	0		X		X		X		
3	4	10.5	0.5	X						X	
4	0.5	14.5	0		X		X			X	
5	5	10	0		X	X			X		
6	7	7	1		X	X				X	
7	0.3	8.3	6.3		X			X	X		
8	0	11	4		X		X		X		X
9	2	13	0		X		X			X	X

TABLE 2-13

Total Life Cycle Cost vs CFA

Unweighted Values of S, M, R

($ x 10^6)

		INTERDATA		DEC		IBM	
		$17/I	$34/I	$17/I	$34/I	$17/I	$34/I
1985 $2M/YR	TOTAL COST	251	341	242	310	259	327
	# SYSTEM PREFERENCES	4	0	11	13	0	2

perturbations. The results show DEC to be the architecture selected predominantly over the others.

e. SUMMARY/CONCLUSION

(1) Summary

The results of the analysis described herein are summarized in Figure 2-2 for the baseline conditions or parameters, namely, an average applications software cost per instruction of $17 in 1976 and a support software investment rate of $2M annually* for the selected CFA to 1985. Figure 2-2 indicates that:

(a) The average total life cycle cost for all 15 systems is estimated at $1.91B in 1976 and $250M in 1985. The average hardware:software ratio decreases from 12:1 in 1976 to 2.4:1 in 1985.

(b) In 1976, the number of systems selecting the PDP-11 architecture on the basis of life cycle cost is the largest (11). The PDP-11 architecture provides the lowest total life cycle cost (8.0% below the average cost) by a small margin (3.7%) over the 8/32 architecture and by a larger margin (20.0%) over the S/370 architecture.

(c) In 1985, the number of systems selecting the PDP-11 architecture continues to provide the lowest total life cycle cost for all 15 systems by margins of 8.8% and 17.6% over the 8/32 and S/370 architectures.

Other baseline conditions applicable to the results shown in Figure 2-2 are: (1) hardware cost reduction 12:1 from 1976 to 1985; (2) hardware life cycle cost is twice the acquisition cost; and (3) software life cycle cost is 5.5 times the acquisition cost.

The results shown in Figure 2-2 are not significantly changed if the average applications software cost per instruction in 1976 is doubled to $34 (thereby decreasing the hardware:software ratio by a factor of 2) or if the annual support software investment for the selected CFA is increased to $3M or decreased to $1M.

(2) Conclusion

The results obtained with the bottom-up life-cycle cost model show that the DEC PDP-11 architecture would provide the lowest life cycle cost for most of the 15 Army embedded-computer systems considered and for the 15 systems as an entity in 1976 and 1985 under the following conditions:

(a) Applications software cost per instruction of $17 and $34 in 1976. Lower costs are assumed in 1985 as the support software base is augmented.

*Editor's Note: M denotes millions of dollars
B denotes billions of dollars

A. AVERAGE TOTAL LIFE CYCLE COSTS ($000,000)

Type Cost	1976	1985
Hardware	$1750	$175
Software	162	75
TOTAL	$1912	$250
HDW/SW Ratios*	12:1	2.4:1

B. 1976 ARCHITECTURE COMPARISON

Architecture	# System Preferences	Relative Total Cost** HDW	SW	Total
8/32	1	.92	1.33	.96
PDP-11	11	.91	1.00	.92
S/370	3	1.16	.67	1.12

C. 1985 ARCHITECTURE COMPARISON

Architecture	# System Preferences	Relative Total Cost** HDW	SW	Total
8/32	-	.92	1.20	1.00
PDP-11	14.5	.91	.91	.91
S/370	0.5	1.16	.91	1.09

* Hardware/software ratios are calculated from cost data detailed in Table 2-8
** 1.00 denotes average cost

Figure 2-2. Summary: Bottom Up Life Cycle Cost Analysis

b. Support software investment rate of $1M, $2M and $3M per year to 1985.

c. Architecture test measures of effectiveness (S, M and R) are weighted for each system application.

d. Hardware cost reduction of 10:1 from 1976 to 1985.

e. Hardware life cycle cost is twice acquisition cost, software life cycle cost is 5.5 times acquisition cost.

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a. APPENDIX A - Computation of Processor Speed and Static Storage Ratios

(1) Introduction

This appendix describes the procedure used to compute the processor speed ratio a_{ij} and the static storage ratio b_{ij}.

(2) Definition of Terms

The architecture test program has defined three terms (S_j, M_j, and R_j) to measure the effectiveness of architecture j.

S_j is a measure of the amount of memory needed to represent a particular test program on the jth architecture.

M_j is a measure of the processor/memory transfers required to execute a particular test program of the jth architecture, i.e., the number of 8 bit bytes that must be read or written by the processor(s) in primary memory.

R_j is a measure of the internal register-to-register transfers required by the processor to execute a particular test program on the jth architecture.

a_{ij} and b_{ij} are factors which act as penalties or bonuses when applied to the cost model. The degree of penalty or bonus is determined by evaluating the results of running the test programs in terms of S, M, and R and calculating a_{ij} and b_{ij} as shown in this appendix.

(3) Architecture Test Results

Twelve test programs listed in Table 2-A.1, each emphasizing a particular type of processing, were run on the candidate architectures. S, M, and R data were collected by S. Fuller at Carnegie Mellon University. For the purposes of this report the multiple values of S, M, and R were averaged and placed into a 12 by 9 matrix. Each row depicts one of the twelve test routines and the nine columns are comprised of an S, M, and R measure for each of the three architectures.

(4) a_{ij}/b_{ij} Computation

A second matrix, 12 by 15, was developed where again each row depicts one of the twelve test routines and each of the fifteen columns represents a prior generation military computer (PGMC). Each element in the m x n matrix consisted of a weight (Wmn) which was subjectively assigned as a measure of the relevance of test program m to PGMC n. Weight assignment was such that any column (system weight set) summed to unity (Table 2-A.2).

The twelve test routines, listed in Table 2-A.1 were considered to fall into one of two categories:

1. Test programs 1, 2, and 3 relate principally to I/O functions.

2. The remaining programs (4-12) are associated with traditional processor/memory functions.

Within these two subsets, varying degrees of functional overlap occur among the test routines.

Table 2-A.1

Architecture Test Programs

1. I/O Kernel, Four Priority Levels
2. I/O Kernel, FIFO Processing
3. I/O Device Handler
4. Large FFT
5. Character Search
6. Bit Test, Set, or Reset
7. Runge Kutta Integration
8. Linked List Insertion
9. Quick Sort
10. ASC II to Floating Point Conversion Routine
11. Boolean Matrix Transpose
12. Virtual Memory Space Exchange

The first weighting step consisted of assigning gross values to categories 1 and 2 for each system. Subsequently, each initially assigned value was distributed across the test routines within the associated category.

Table 2-A.2

Weights Assigned To Each System To Emphasize or De-Emphasize The Relative Importance Of The Test Program To The System

SYSTEM #	TEST PROGRAM A	B	C	D	E	F	G	H	I	J	K	L
1	.15	.05	.20	.10	.15	.05	.05	0	.10	.05	.05	.05
2	.15	.05	.15	0	.20	.05	.25	0	.05	0	.05	.05
3	.15	.05	.15	0	.35	.05	.10	0	.05	0	.05	.05
4	.20	.05	.20	0	.20	.05	.15	0	.05	0	.05	.05
5	.15	.10	.15	0	.30	.05	.10	0	.05	0	.05	.05
6	.20	.05	.15	0	.25	.05	.05	.05	.10	0	0	.10
7	.20	.05	.20	0	.15	.05	.30	0	.05	0	0	0
8	.20	.05	.20	0	.25	.10	.05	.10	.05	0	0	0
9	.05	.15	.30	0	.35	.05	.05	0	.05	0	0	0
10	.15	.05	.40	0	.25	.05	.05	0	.05	0	0	0
11	.20	.10	.10	0	.35	.05	.10	0	.05	0	0	.05
12	.20	.05	.20	0	.20	0	.05	.10	.10	0	0	.10
13	.10	.05	.20	.05	.30	.05	.10	0	.05	.05	0	.05
14	.20	.05	.35	0	.20	.05	.05	0	.05	0	0	.05
15	.10	.10	.15	0	.05	.20	.40	0	0	0	0	0

For example, the Combat Service Support System (CS3) resembles contemporary commercial data processing in its use of COBOL and data bases. Thus, its weighting was positively biased toward I/O and processing routines such as "Linked List Insertion," and negatively biased with regard to mathematical oriented routines such as "Runge Kutta". On the other hand, the Tank Ballistics Application Computer System will be used primarily to perform trajectory computations - its weighting favored "Runge Kutta" but was biased against "Linked List Insertion."

The values of S, M, and R in the 12 x 9 matrix then are normalized by row and multiplied, element by element, by the 12 x 15 matrix of test program weights.

$$S_{3,2} = W_{13}\, S_{12} + W_{23}\, S_{22} + W_{33}\, S_{32} + \cdots + W_{12,3}\, S_{12,2}$$

Similarly, for system 3, values of S were found for the first and third architectures, i.e., $S_{3,1}$ and $S_{3,3}$. An average S was then calculated for system 3.

$$S_3 = \frac{S_{3,1} + S_{3,2} + S_{3,3}}{3}$$

The value of b for system 3 in architecture 2 was found by solving for:

$$b_{3,2} = \frac{S_{3,2}}{S}$$

In this manner, a value of b for each system in each architecture (15x3) was calculated. These results are shown in Table 2-A.3.

The ratio a_{ij} was determined from the general relationship

$$a = \frac{3 \sum MW + \sum RW}{3\,M + R}$$

The actual procedure of multiplying corresponding elements of the two matrices is identical to that used in the solution of the ratio b_j and will not be repeated here. As in b_j, a value of a was calculated for each system in each architecture. The results are shown in Table 2-A.3.

Table 2-A.3

Static Storage Ratio and Processor Speed Ratios for Each Architecture

	SYSTEM MISSION	PROCESSOR SPEED RATIO, a_{ij}			STATIC STORAGE RATIO, b_{ij}		
		INTER-DATA 8/32	DEC PDP-11	IBM S370	INTER-DATA 8/32	DEC PDP-11	IBM S370
1	Medium Search	0.81	0.92	1.28	0.84	0.93	1.24
2	Medium Command and Control	0.81	0.81	1.39	0.86	0.85	1.30
3	Small Search	0.84	0.78	1.28	0.88	0.83	1.28
4	Large Command and Control	0.79	0.78	1.44	0.81	0.81	1.38
5	Medium Command and Control	0.81	0.78	1.41	0.85	0.82	1.32
6	Large Command and Control	0.79	0.83	1.38	0.84	0.84	1.32
7	Small Command and Control	0.77	0.77	1.47	0.81	0.82	1.37
8	Large Communications	0.81	0.75	1.46	0.84	0.80	1.37
9	Small Communications	0.89	0.83	1.29	0.95	0.80	1.19
10	Small Communications	0.87	0.79	1.35	0.90	0.82	1.29
11	Small Special Purpose	0.78	0.73	1.49	0.83	0.78	1.39
12	Large Data Management	0.80	0.85	1.36	0.83	0.85	1.32
13	Medium Search	0.89	0.83	1.28	0.92	0.88	1.21
14	Medium Data Management	0.83	0.77	1.41	0.84	0.79	1.37
15	Small Guidance and Control	0.80	0.76	1.42	0.86	0.82	1.32

3. THE TOP-DOWN MODEL

a. INTRODUCTION

This paper describes the mathematical formulation, parameter sensitivity, and error analysis of a life-cycle cost model for comparing computer architectures. The model quantitatively compares computer architectures by projecting trends and combining estimates of architecture-dependent hardware and software costs to obtain discounted life-cycle costs and cost ratios.

The model was developed in order to help the Army and Navy determine the most cost effective of three candidate computer architectures, with the intent that this architecture would be the basis of a software compatible family of military computers over the 1978-1990 time period [EsteR76]. The three candidate architectures were the IBM S/370, the Digital Equipment Corporation PDP-11, and the Interdata 8/32. In addition to describing the model, this paper gives the input data and the results of comparing these architectures.

By selectively perturbing the expected values of key parameters and observing the effects, we were able to determine the sensitivity of the model to uncertainties in the input data and to determine the relative importance of each piece of input data. In comparing the IBM S/370, the Digital Equipment Corporation PDP-11, and the Interdata 8/32 computer architectures over the 1978-1990 time frame, the model indicated that the relative cost effectiveness of these architectures was most sensitive to the software-to-hardware ratio of the computing environment and to the support-software base available for each architecture.

The major findings were that for support-software base of about 2 million dollars per year, the IBM S/370 architecture was the most cost effective for software-to-hardware (S/H) greater than about one, while for S/H ratios less than about one fourth the Interdata 8/32 was superior. For intermediate values of S/H the DEC PDP-11 was superior. These findings must, however, be viewed in light of the fact that error analysis shows the uncertainty on the cost ratios to be large compared to the cost ratio differences among the architectures.

Before describing the model, it may be helpful to clarify what we mean by "computer architecture." Although many, often conflicting, definitions of this term appear in the literature, the joint Army/Navy Computer Family Architecture (CFA) Selection Committee [SmitW75, ColeA76, SaliA76] has defined it to be the abstract view of a computer as seen by an assembly language programmer. This view includes the instruction and register sets, interrupt structure, and memory addressing scheme; it excludes hardware attributes, such as cycle time, microprogrammed vs hardwired logic implementations, instruction look-ahead schemes, memory interleaving and cache memories, that are normally transparent to the assembly language programmer. A more precise statement of the Selection Committee's definition appears in Volume 1 of this set of reports.

The Garbage-In-Garbage-Out (GIGO) principle applies to cost models. Cost models often require as input estimates of, among other things: initial investments, service lives, salvage values, operating costs, and the cost of money. Given that most of these involve a forecast of the future, their preparation is a difficult task. Although we can be guided by our own past experiences, the experiences of others, the opinions of qualified personnel, and the results of pilot studies, a degree of uncertainty is always present. This uncertainty does not, however, mean that it is fruitless to adhere to quantitative analytical

techniques because the alternative leads to decisions based solely on judgment and intuition and having a probability of error higher than that of the quantitative approach. A quantitative approach compels the involved individuals to state their estimates explicitly and, unlike the qualitative approach, assures that these data can be subjected to critique and analyzed in a rational manner.

The decision making process usually involves the following four steps:

Step 1) Define the Alternatives
Step 2) Describe the Alternatives
Step 3) Evaluate the Alternatives
Step 4) Consider the Irreducibles

For the CFA project, the first step, define the alternatives, had already been carried out by the Selection Committee before work on the cost model desribed below began. The identified alternatives were to standardize on either:

1) the IBM S/370 architecture,
2) the Digital Equipment Corporation (DEC) PDP-11 architecture, or
3) the Interdata 8/32 architecture

Restricting the life-cycle cost comparisons to these architectural alternatives simplifies the cost model because parameters that might normally be included in the model can be ignored if they are invariant over the architectural alternatives.

The second and third steps (describe and evaluate the alternatives) fall within the domain of the cost model.

The fourth step, consider the irreducibles, can be an important part of the decision process. By irreducibles we mean attributes of the alternatives that have not been, or cannot be, quantitatively described by the model. An example of an irreducible is the willingness of each manufacturer to assist in verifying and establishing his architecture if it is selected. The final decision on the most desirable alternative should consider irreducibles in inverse proportion to the size of the model-generated cost differences between the alternatives. The smaller the differences, the more consideration should be given to irreducibles. Volume eight, final selection, discusses the irreducibles relevant to the CFA project.

b. THE BASIC MODEL

The principal output of the model is a two-dimensional matrix, R*, whose elements, R^*_{jk}, j=1, ...N_y, k=1, ..N_a, give the discounted cumulative cost of architecture k relative to a reference architecture for a period of j years. Here N_y denotes the maximum time period in years and N_a the number of architectures under examination. An element R^*_{jk} is called a discounted cumulative cost ratio. If the model yields $R^*_{m1} < R^*_{m2}$, then, neglecting irreducibles, architecture 1 is more desirable than architecture 2 for the period j=1 through j=m, since it has a lower cumulative cost for that period.

The study described herein examines cumulative costs over periods of one to thirteen years (N_y=13) beginning in 1978. Cumulative costs were calculated only

up to 1990, j=13, because of the increasing difficulty of estimating meaningful values of input parameters with time. Since this study compares only three architectures, we have $N_a=3$. The index k=1 represents the IBM S/370 computer family architecture (the reference architecture), k=2 the Digital Equipment Corporation PDP-11 architecture, and k=3 the Interdata 8/32 architecture.

The model obtains the yearly architecture-dependent cost (C_{jk}) by summing the architecture-dependent hardware costs (H_{jk}) and software costs (S_{jk}),

$$C_{jk} = S_{jk} + H_{jk}. \tag{3.1}$$

The nondiscounted cumulative cost through year m for architecture k, D_{mk}, is simply the sum of all costs from year 1 through year m,

$$D_{mk} = \sum_{j=1}^{m} C_{jk} \tag{3.2}$$

The discounted cumulative cost, D^*_{mk}, on the other hand, takes into account the time value of money. Since, ignoring inflation, a dollar today is worth more than a dollar tomorrow, the model multiplies cash flows occurring in a year j by a discount factor, d_j, and sums the products,

$$D^*_{mk} = \sum_{j=1}^{m} C_{jk} d_j. \tag{3.3}$$

Each discount factor is an average over the year j of the single-payment present-worth factor w^{-t}, where

$$w = 1 + q/100 \tag{3.4}$$

and q is the annual discount rate in percent. More specifically, d_j is given by

$$d_j = \int_{j-1}^{j} w^{-t} dt \Big/ \int_{j-1}^{j} dt \tag{3.5}$$

$$= (w^{1-j} - w^{-j})/\ln(w)$$

These discount factors are the same as those recommended in [AFR--69] and used in [SADPR74, Volume V].

Since our immediate interest is only in the relative merits of the three architectures, their cumulative cost ratios provide an adequate and useful measure. In addition, the cost ratios are more useful than absolute costs because they serve to cancel out common and possibly unknown multiplicative factors.

Taking architecture one (the IBM S/370) as the reference architecture, we define the nondiscounted cumulative cost ratio as

$$R_{jk} = D_{jk}/D_{j1}, \tag{3.6}$$

and, analogously, the discounted cumulative cost ratio as

$$R^*_{jk} = D^*_{jk}/D^*_{j1}. \tag{3.7}$$

Consequently, we have $R^*_{j1} = R_{j1} = 1$ for $j=1,\ldots N_y$.

(1) Architecture-Dependent Hardware Costs

The model obtains the architecture-dependent hardware costs (H_{jk}) by summing the architecture-dependent processor (P'_{jk}), main-memory (M'_{jk}), and secondary-memory (E'_{jk}) expenditures,

$$H_{jk} = P'_{jk} + M'_{jk} + E'_{jk}. \tag{3.8}$$

The following sections describe the method of arriving at values for these expenditures.

(a) System Development Cycle and Yearly Hardware Expenditure

Total yearly hardware expenditures, B_j, $j=1 \ldots N_y$, for CFA-related military computer systems are key inputs to the model. They include computer, main-memory, secondary-memory, I/O and peripheral devices, and related expenditures.

Estimating realistic values for B_j, $j=1, \ldots N_y$ is a problem since both the number of dollars that will be spent on future DoD military computer systems and the fraction of these dollars that will fall under the jurisdiction of the CFA project are unknown at this time. Fortunately, however, the relative merits of the competing architectures as measured by the model are insensitive to multiplying all the yearly hardware expenditures, B_j, $j=1, \ldots N_y$ by the same constant because, neglecting the relatively small yearly support-software expenditures, the constant divides out of the model's equations when we compute the total cumulative-cost ratios. The relative amount spent for hardware in a given year as compared with other years is a more important figure.

Military systems typically require years between initiation of development and full deployment. This phasing-in period is estimated to be approximately equal to average system development cycle time, which experience indicates runs between 3 and 10 years [KossA75], [ChapG73], [PremA76], [BoehB73b, p. 15]. In order to approximate the expenditure levels during this phasing-in period, we assumed that the expenditures B_j, $j=1, \ldots N_y$, began at some predetermined level,

B_1, increased linearly with time over an initial development period (B_j, j=1, ...N_d), and then remained constant for the remaining period (B_j, j=N_d+1, ..N_y). For the purpose of the study, the development period, N_d, was estimated to be seven years. The sensitivity studies (Cases 31 and 32) also considered the effects of choosing development periods of five and ten years, assuming the same initial and final hardware expenditure levels. The simplifying assumption of constant base hardware expenditures after an initial development period appears to be reasonable because: (1) total ADP expenditures in DoD, when measured in uninflated dollars, have been nearly constant in recent years; (2) the principle of level funding has tended to guide DoD budget allocations; (3) decreasing hardware costs on a per-unit basis have tended to offset increasing hardware requirements; and (4) the exact dollar assumption used is less important than its equal-handed application to each of the candidate architectures.

Although they are few and far between, there are some estimates and projections of computer system budgets available today [FisnD74, BoenB72, SADPR74, WithF75]. For our purposes, one of the more useful was D. A. Fisher's study of ADP costs in DoD [FishD74]. In this report, Fisher estimated that in FY 1973, DoD spent 6.2 to 8.3 billion dollars on ADP. He found that approximately one third of this amount originated in each service, and that about 16% of the total went to computer hardware, 45% went to software, and 38% to other ADP costs, such as support and supplies, keypunching, and computer operation. Using these figures, we deduce that 1.0 to 1.3 billion dollars went to computer hardware and roughly 2.8 to 3.7 billion dollars went to software. During a private conversation with the author in May, 1976 [FishD76], D. Fisher mentioned that his recent studies showed that if one were to divide DoD software costs by application, the major portion (approximately 56%) goes for embedded computer systems, i.e., the types of systems the CFA project is designed to influence. Approximately 19% goes for administrative data processing applications wherein COBOL is the principal language, and 5% goes to scientific applications using most commonly FORTRAN. The other 20% goes for other types of applications and indirect costs. Assuming these percentages also applied in FY 1973, this would mean that of the approximately 2.8 to 3.7 billion that went to software, about 1.6 to 2.1 billion went for software for embedded computer systems. If we make the assumption that the software-to-hardware cost ratio for embedded computer systems is approximately the same as that for overall DoD ADP systems, we obtain 0.6 to 0.7 billion dollars for hardware for embedded computer systems. Dividing this by three to obtain an estimate of cost for each service, we obtain 0.2 to 0.23 billion. Of course, not all embedded computer systems will be impacted by CFA. Making the very rough assumption that one fourth would be, we obtain a yearly annual hardware expenditure rate for a single service of about 50 million dollars. For the purpose of our study, we took this figure as our nominal hardware expenditure level.* We also assumed, based on the seven year phase-in period described earlier, that the initial hardware expenditure was about one-seventh of this, or 7 million dollars. In summary, for most of the cases reported in this study, we assumed the yearly base hardware expenditures will remain constant at fifty-million dollars after linearly increasing over a seven-year development period from approximately seven million dollars.

*As pointed out earlier, the overall expenditure level assumed is immaterial since it is the comparative (not absolute) costs that are being computed.

(3) Nominal Yearly Processor Expenditures

The model assumes that the nominal yearly processor expenditures (K_j) are constant (u) times the yearly base hardware expenditures (B_j),

$$K_j = uB_j. \tag{3.9}$$

Nominal processor expenditures (K_j) comprise the nominal CPU (P_j) and nominal main memory (M_j) expenditures but exclude expenditures for I/O busses, devices, and other peripheral gear whose costs are insensitive to the architecture of the processor,

$$K_j = P_j + M_j. \tag{3.10}$$

We assumed in most cases that the constant u was 0.5; that is, we took the total yearly CPU and main memory costs to be one-half the overall CFA base hardware expenditures. This assumption roughly agrees with a recent survey of DP budgets [McLaR76]. In order to measure the sensitivity of the model to u, we also used values of 0.4 and 0.6 as explained in Section 3.

(b) Yearly Main Memory Expenditures

The model assumes the nominal yearly main memory cost (M_j) is a fraction (α) of the nominal yearly processor expenditures (K_j),

$$M_j = \alpha K_j. \tag{3.11}$$

Based on data on military computer systems found in [KossA75], and [SDC-76a] it appears that α usually lies between 0.5 and 0.8. The value used in most of our calculations was 0.65.

Although nominal main-memory cost is not architecture dependent, actual main-memory cost (M'_{jk}) is. We express this dependency as follows:

$$M'_{jk} = p_k s_k a M_j. \tag{3.12}$$

The two coefficients, p_k and s_k, are included in this equation because the cost of memory depends upon the efficiency with which an architecture stores programs as well as the rate at which it uses memory in executing them. The parameter s_k, the normalized s-measure, is indicative of the memory space required to represent a program when using architecture k. This space includes all the storage required to represent and execute the program exclusive of input/output used by the program (since the same data arrays are used by all candidate architectures). Professor S. Fuller and other members of the computer science department of Carnegie-Mellon University, with the assistance of Army and Navy R/D organizations, obtained the s-measures and also the m- and r-measures reported below by programming a set of test (benchmark) programs on existing machines of the candidate architectures and then normalizing the results [FullS76]. The quantity p_k in equation (3.12) is a cost-to-performance coefficient for architecture k which the model obtains by combining the normalized m and r-measures as follows:

$$p_k = (Vr_k + Wm_k)^{1/g} \tag{3.13}$$

The m-measure, m_k, is a measure of the traffic between main memory and the central processor that is required to execute a program when using architecture k. The r-measure, r_k, is a measure of the data traffic internal to the central processor. The exponent g follows from a general relationship, probably first examined by Grosch [GrosH53], between performance and cost, i.e., performance = K x $cost^g$. Rein Turn [TurnR74] gives a value of g between 2 and 3; the SADPR-85 Study Group [SADPR74], using more recent data, argues for a lower value of about 1.5. Although this latter value was used in most of our calculations, we also investigated the effects of using values of 1 and 2 (Section 3). The parameters V and W are weighting factors for the r- and m-measures. Their sum is assumed to be one. Because the values obtained for the r- and m-measures are almost equal for each of the candidate architectures, making r_k insensitive to the values of V and W, we took both V and W to be 0.5.

The constant a appears in equation (3.12) because parts of the main memory are insensitive to computer architecture - in particular, the portion occupied by data arrays. The architecture sensitive fraction, a, is called the main-memory static-storage ratio. Most of the calculations assume a equals 0.8. The sensitivity studies, however, also examine the effects of using values of 0.7 and 0.9.

(c) Yearly Central Processor Expenditures

The nominal yearly and architecture-independent central processor expenditures (P_j) follow from combining equations (3.10) and (3.11),

$$P_j = (1-\alpha)K_j. \tag{3.14}$$

The actual architecture-dependent central-processor expenditures (P'_{jk}) are given by:

$$P'_{jk} = P_k P_j \tag{3.15}$$

(d) Yearly Secondary Memory Expenditures

The model assumes the nominal secondary-memory expenditures (E_j) are independent of nominal processor costs (K_j) and are a fraction, v, of the yearly base hardware expenditures (B_j), i.e.,

$$E_j = vB_j. \tag{3.16}$$

From these it obtains the secondary-memory expenditures that are architecture-sensitive by

$$E'_{jk} = bs_k E_j. \tag{3.17}$$

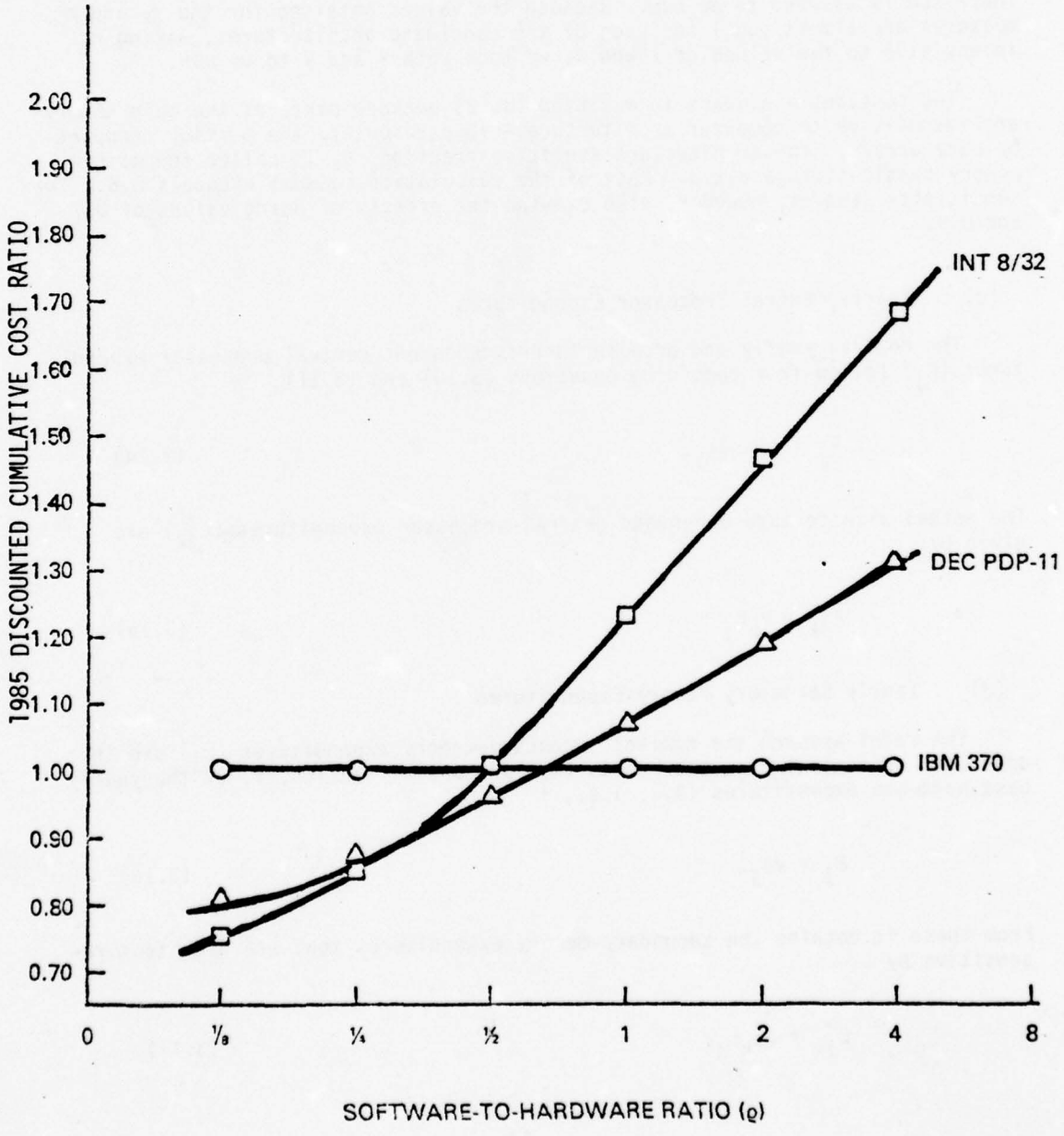

SUPPORT SOFTWARE EXPENDITURE, $O_j = 2 \times 10^6$
1985 CURVES
1985 DISCOUNTED CUMULATIVE COST RATIO
2.00
1.90
1.80
1.70
1.60
1.50
1.40
1.30
1.20
1.10
1.00
0.90
0.80
0.70
INT 8/32
DEC PDP-11
IBM 370
0
1/8
1/4
1/2
1
2
4
8
SOFTWARE-TO-HARDWARE RATIO (ϱ)

Figure 3-1

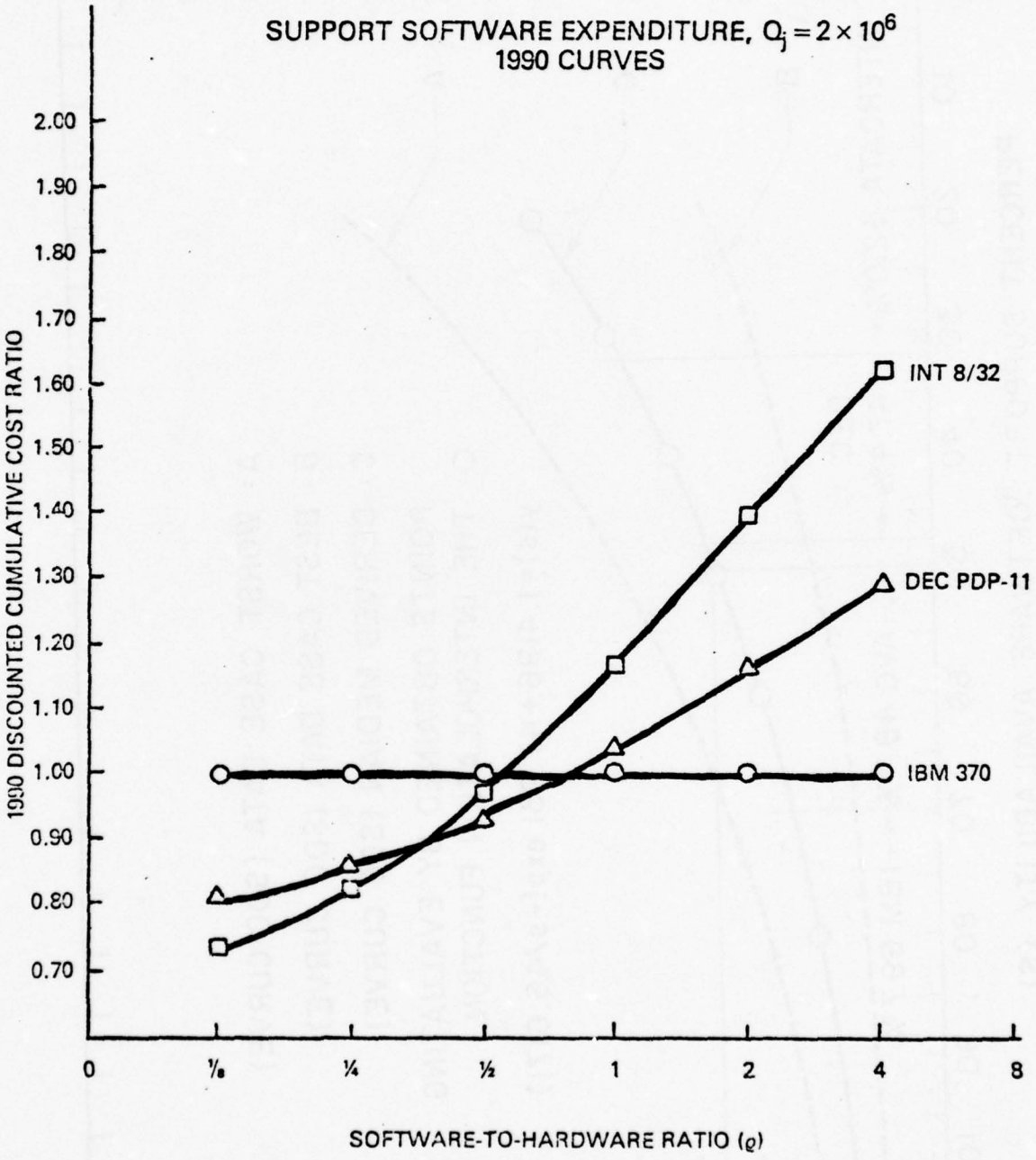

SUPPORT SOFTWARE EXPENDITURE, $Q_j = 2 \times 10^6$
1990 CURVES
1990 DISCOUNTED CUMULATIVE COST RATIO
2.00
1.90
1.80
1.70
1.60
1.50
1.40
1.30
1.20
1.10
1.00
0.90
0.80
0.70
INT 8/32
DEC PDP-11
IBM 370
0
⅛
¼
½
1
2
4
8
SOFTWARE-TO-HARDWARE RATIO (ϱ)

Figure 3-2

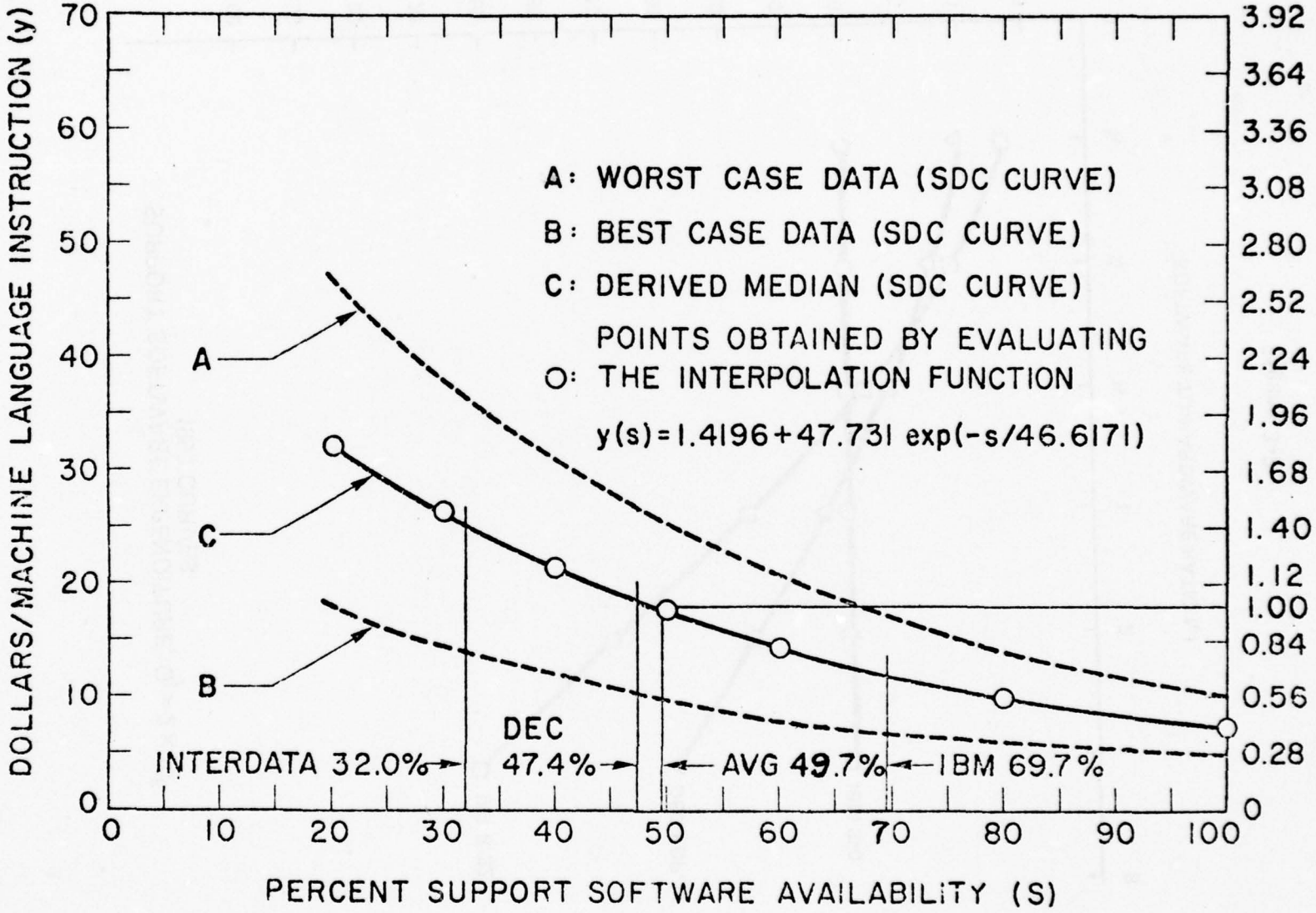

DOLLARS/MACHINE LANGUAGE INSTRUCTION (y)
70
60
50
40
30
20
10
0
SUPPORT SOFTWARE FACTOR (F); k = 0.056
3.92
3.64
3.36
3.08
2.80
2.52
2.24
1.96
1.68
1.40
1.12
1.00
0.84
0.56
0.28
0
A: WORST CASE DATA (SDC CURVE)
B: BEST CASE DATA (SDC CURVE)
C: DERIVED MEDIAN (SDC CURVE)
POINTS OBTAINED BY EVALUATING
O: THE INTERPOLATION FUNCTION
y(s)=1.4196+47.731 exp(-s/46.6171)
A
C
B
INTERDATA 32.0%
DEC
47.4%
AVG 49.7%
IBM 69.7%
0
10
20
30
40
50
60
70
80
90
100
PERCENT SUPPORT SOFTWARE AVAILABILITY (S)

Figure 3-3

The constant b, the secondary-memory static-storage ratio, is analogous to the main-memory static-storage ratio (a), and the parameter, s_k, is the normalized s-measure discussed in Section 3.2.1.3.

Although it is difficult to determine the value of v that is appropriate to military computer systems, its value is not critical for two reasons: (1) v is small (less than 0.2) for most military computer systems and (2) the fraction of v that is architecture related, i.e., the secondary-memory static-storage ratio (b), is also small (less than 0.2) [SDC-75], [KossA75]. Most of the calculations of this study take v to be 0.1 and b to be 0.2. The sensitivity studies discussed in Section 3 examine the effects of choosing v equal 0.0 and 0.2 and b equal 0.1 and 0.3, and confirm the relative insensitivity of the model to uncertainties in the values of these parameters.

(2) Architecture-Dependent Software Costs

For architecture k, the total yearly software expenditure (S_{jk}) of eq. 3.1 is the sum of the yearly support-software expenditure (Q_j) plus the architecture-dependent application-software expenditure (A_jF_{jk}),

$$S_{jk} = Q_j + A_jF_{jk} \qquad (3.18)$$

(a) Yearly Support Software Expenditures

We define support software to be software tools such as compilers, loaders, linkers, simulators, assemblers, sub-monitors, operating systems, and debug packages and we assume that the amount of money allocated for the development of these tools is independent of the architecture chosen. Hence, the model assumes that support software will be developed with an expenditure of Q_j dollars for each year j where j=1, ...13. For the cases considered in this paper, we let value Q_j be constant at x million dollars, for j=2 through 13 and Q_1=0. The sensitivity studies examined the effects of allowing x to range from zero to eight million dollars in two million dollar increments. Although x is architecture independent, it plays a dominant role in determining the lowest cumulative cost alternative. Unless an extremely small CFA program is envisioned, e.g., 5 million dollars per year or less, the support-software costs will be small compared with applications-software costs, and probably will be around 2 million dollars per year.

(b) Architecture-Dependent Applications-Software Costs

The model assumes that base (or nominal) applications-software expenditure in year j, denoted A_j, is a constant (ρ) times the yearly base hardware expenditure, B_j,

$$A_j = \rho B_j \qquad (3.19)$$

For lack of a better name, we call ρ the software-to-hardware ratio. Working with the reports of Fisher [FishD74], and others [WithR75], [TurnR74], [BoehB72], [McLaR76], [SADPR74], we estimate ρ to be about 2.5 to 3 for general-purpose DoD computer systems, and possibly 1/2 to 2 for embedded (tactical) systems [CnapG73], which usually have multiple deployments of the same software and hardware and do not have software bundled into the system price.

The constant ρ is one of the most crucial parameters in the model. Because of its importance and because of the difficulty of estimating its value, we determined the cumulative-cost ratios for 1985 and 1990 using values of ρ of 1/8, 1/4, 1/2, 1, 2, and 4. Figures 3-1 and 3-2 show the results of these calculations for support-software expenditures (Q_j) of two million dollars and clearly illustrate the importance of ρ in determining the most cost-effective computer family architecture.

At this point, a word of warning appears to be necessary. The sensitivity studies, to be described in Section 3.3, show that the expected uncertainties of the values of the input parameters can result in substantial uncertainties in the cumulative cost ratios. They imply that the reader should interpret the PDP-11 and Interdata 8/32 curves of Figures 3-1 and 3-2 as ribbons having widths on the order of twenty to thirty percent of the illustrated values; the choice of the most desirable architecture for values of ρ between 1/4 and 2 (the values expected in the military computing environment) is by no means clear. As a consequence, the final decision should examine irreducibles.

The architecture-dependent applications-software costs, mentioned earlier, are $A_j F_{jk}$. Here F_{jk} is the amount of base (nominal) applications-software expenditure that should be used in determining the actual applications-software cost for architecture k. It is dependent upon the available support software for architecture k in year j.

In order to derive an expression for F_{jk} we began with the curves shown in Figure 3-3. These curves give the cost per machine language instruction as a function of available support software. One-hundred percent support software means that an "ideal" set of software tools for military computer systems is available. W. Svirsky, T. Giles, and A. Irwin of System Development Corporation, West Long Beach, New Jersey, generated these curves on the basis of the results of a questionnaire sent to SDC project managers of five large scale (24K to 500K instructions) command and control software efforts [SDC76b], [SvirW76]. The program managers responded to the questionnaire by providing: the cost of software production, the number of instructions generated, the expected percentage increase in project cost that would result if each of thirteen software tools available to them had not been used, and the expected percentage decrease in project cost that would result if an ideal software tool were available. Taking the median of the best and worst case data curves, Svirsky, Irwin and Giles also derived curve C. They noted, however, that the curves are largely judgmental and examples can be found that yield costs per instruction above and below the worst and best case data. Confirming their reservations, we note that the values of cost per instruction shown in Figure 3-3 are lower than those reported by Wolverton [WolvR74] and others [BrooF75], [TabaM74], [PremA76]. Although he does not cite any figures, Manley has found, and gives reasons why, in general the cost per instruction for embedded computer systems is significantly higher than that for normal data processing systems [ManlJ74]. At a September, 1973 symposium, B. Boehm mentioned that Air Force avionics software costs something like $75 per instruction to develop, and that maintenance of the software has run up to $4000 per instruction [BoehB73]. The absolute cost per instruction does not affect the Top Down model, however, because the model depends only upon the relative cost-per-instruction vs support software, as opposed to the absolute cost given by the curve.

From a graph of the SDC median curve, it appeared to us that the interpolation function

$$y(s') = y_m + (y_M - y_m)\exp(-s'/c) \qquad (3.20)$$

might provide a reasonably good fit. Here y is the dollars per machine language instruction, s' is the support software availability in percent, and y_m, y_M, and c are constants. Insisting that this function pass through the three points (s', y) = (20, 32.5), (50, 17.75), and (80, 10), in accordance with the SDC supplied curve, we obtained y_m=1.4196, y_M=49.151 and c=46.6171. Next we assumed that

$$F_{jk} = k'y(s'), \qquad (3.21)$$

where k' is a constant whose value is determined by the additional assumption that when the average of the available support software of the three alternative architectures in year 1, call it s', is substituted in equation (3.21) for s' we should obtain $F_{jk} = 1$. Here we assume s' can be expressed as

$$s' = \frac{100}{3}\left(\frac{U_{11}}{T_1} + \frac{U_{12}}{T_2} + \frac{U_{13}}{T_3}\right), \qquad (3.22)$$

where U_{jk} denotes the available support software (measured in dollars) in year j for architecture k, and T_k the dollar value of a 100% support-software base (or ideal support-software base) for architecture k.

Several members of the CFA selection committee surveyed the industry and estimated values for the currently existing support-software base for each candidate architecture and also estimated T_k. The values they came up with were:*

	k	Currently Available Support Software Base ($)	T_k ($)
IBM 370	1	31.049M	44.604M
DEC PDP-11	2	20.790M	43.893M
INT 8/32	3	14.100M	44.040M

Making the assumption that the currently available support-software base values given above could be used in the model for U_{1k}, k=1, ..3, we obtained from equation (3.22) that s' = 49.7, and

$$k' = 1/y(s') \qquad (3.23)$$

$$= 0.05601$$

*M denotes millions. See Appendix B, Section 3.7 for corrections to these figures.

Figure 3-3 shows the results. Expressing F_{jk} as

$$F_{jk}=f_m+(f_M-f_m)\exp(-nU_{jk}/T_k), \tag{3.24}$$

we have

$$f_m=k'y_m=0.0795 \tag{3.25}$$

$$f_M=k'y_M=2.7528 \tag{3.26}$$

and

$$n=\frac{100}{c}=2.1451. \tag{3.27}$$

The dollar value of the available support software in year j for architecture k, U_{jk}, is given by

$$U_{jk}=U_{1k}+\sum_{m=2}^{j} Q_m, \tag{3.28}$$

where Q_m is dollar expenditure for support software in year m.

The values of Q_m have a significant impact on the results of the model. Demonstrating this impact, *Figures 3-4 and 3-5 show discounted total cumulative* cost ratios for 1985 and 1990. The cases shown assume that $Q_m = x$ for m=2, ...13 and that x ranges from 0 to 8 million dollars in 2 million dollar increments, and that ρ varies by doubling from 1/8 to 4. Figures 3-1 and 3-2 are, of course, subsets of these results. These figures show that by increasing support-software expenditures we can effectively counter high values of ρ that may be characteristic of certain computing environments. They also show that as support-software expenditures increase, the differences between the three candidate architectures decrease. For low values of ρ the Interdata 8/32 appears most desirable, for high values of ρ the IBM S/370 appears to be the best choice; for intermediate values of ρ (between 1/4 and 1) the DEC PDP-11 may be best. As mentioned earlier, because of the uncertainties of the input parameters, these results should be interpreted with discretion.

The trend from case 4 to case 5 (shown in figure 3-4) may at first appear a little perplexing. It indicates that if we increase the expenditure rate for support software development, the PDP-11 and Interdata 8/32 get worse relative to the IBM S/370. One might guess that they would get better. The reason they don't improve is because a point of diminishing returns has been reached. In case 5 we are spending 8 million dollars per year on support software, when the maximum base applications software expenditure is only 6.25 million. Hence, the amount spent on support software is more significant than the amount of reduction it causes in applications software expenditures. Since the cumulative hardware costs for the Interdata and DEC are lower than the hardware costs of the IBM S/370, increasing the support software expenditure in this manner only makes them appear worse, rather than better.

CASE	ϱ	Q_j ($MIL)	CASE	ϱ	Q_j ($MIL)
1	1/8	0	16	1	0
2	1/8	1	17	1	1
3	1/8	2	18	1	2
4	1/8	4	19	1	4
5	1/8	8	20	1	8
6	1/4	0	21	2	0
7	1/4	1	22	2	1
8	1/4	2	23	2	2
9	1/4	4	24	2	4
10	1/4	8	25	2	8
11	1/2	0	26	4	0
12	1/2	1	27	4	1
13	1/2	2	28	4	2
14	1/2	4	29	4	4
15	1/2	8	30	4	8

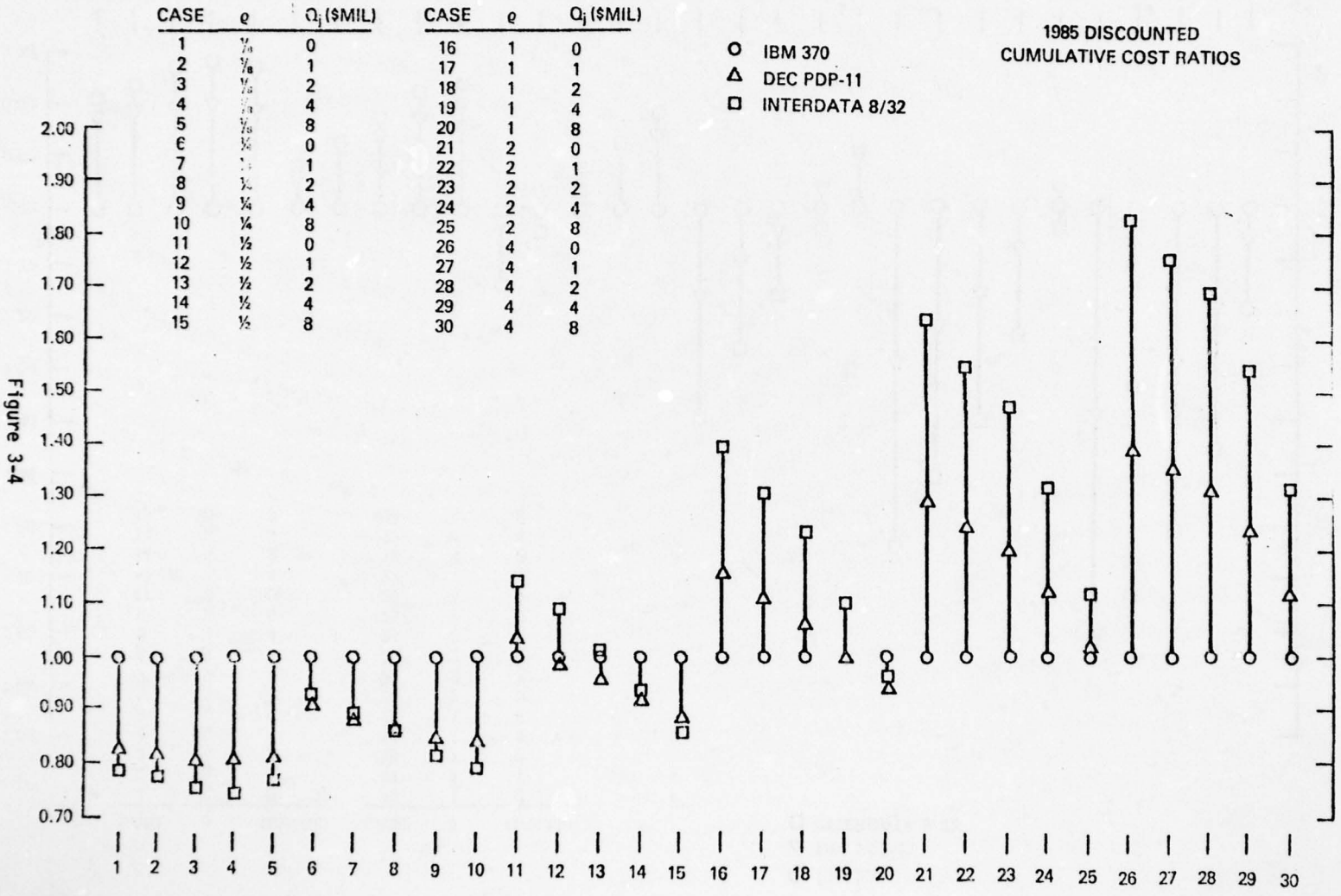
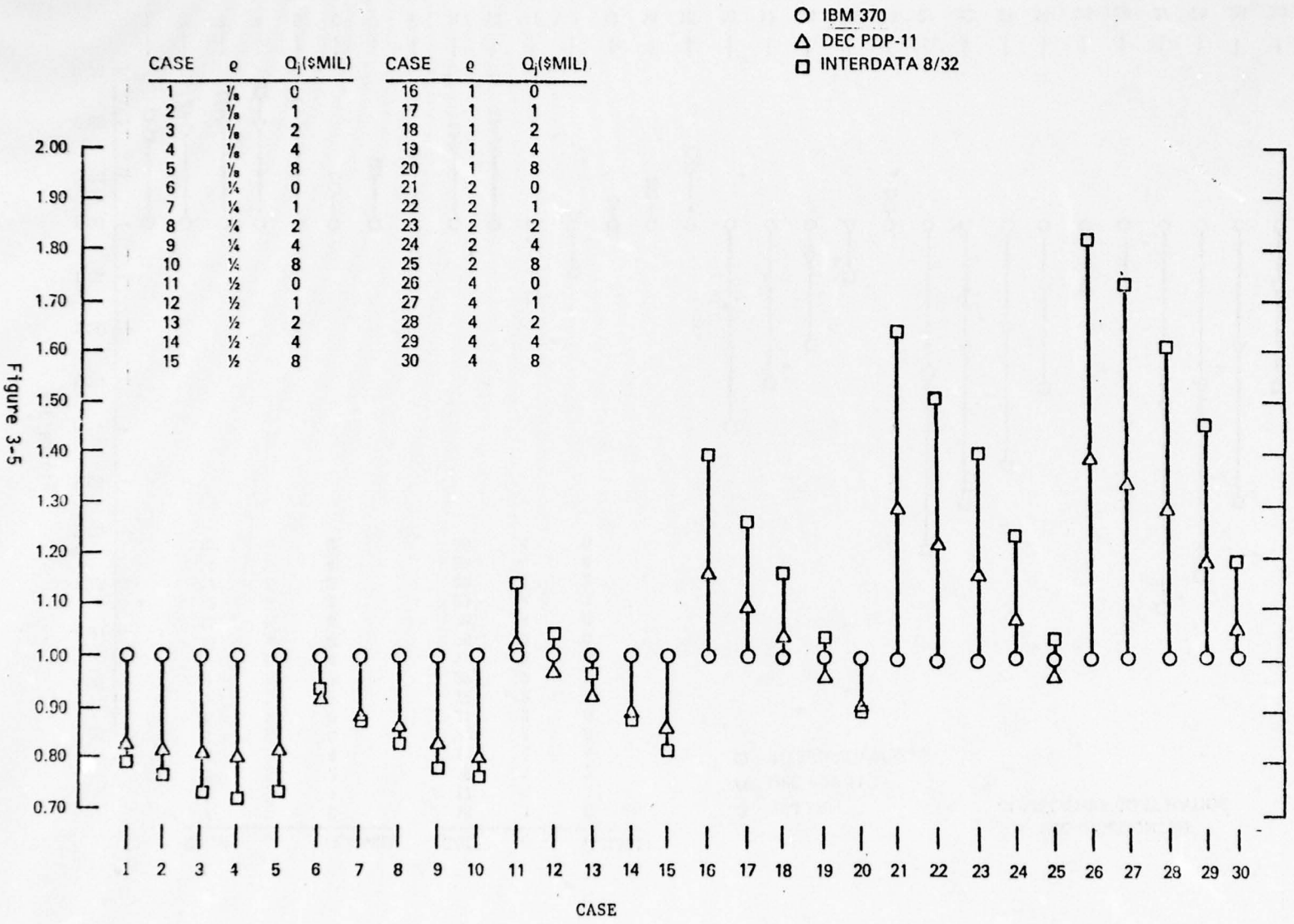


Figure 3-4

1990 DISCOUNTED CUMULATIVE COST RATIOS



CASE	ϱ	Q_j($MIL)	CASE	ϱ	Q_j($MIL)
1	1/8	0	16	1	0
2	1/8	1	17	1	1
3	1/8	2	18	1	2
4	1/8	4	19	1	4
5	1/8	8	20	1	8
6	¼	0	21	2	0
7	¼	1	22	2	1
8	¼	2	23	2	2
9	¼	4	24	2	4
10	¼	8	25	2	8
11	½	0	26	4	0
12	½	1	27	4	1
13	½	2	28	4	2
14	½	4	29	4	4
15	½	8	30	4	8

Figure 3-5

(3) Architecture-Dependent License/Royalty Costs

Architecture license fees or royalties most likely will have to be paid to the selected manufacturer for using his architecture and software. These may be paid in a lump sum in the beginning or as a percentage of each computer as it is manufactured. Since they are expected to be a relatively small fraction of the overall life cycle costs, the model does not account for them.

(4) Summary of Equations

The equation numbers of this section are those used in the previous text.

For $j = 1, ..N_y$ and $k = 1, ..N_a$

$$A_j = \rho B_j \qquad (3.19)$$

$$K_j = P_j + M_j = uB_j \qquad (3.9 \text{ and } 3.10)$$

$$M_j = \alpha K_j \qquad (3.11)$$

$$P_j = (1-\alpha)K_j \qquad (3.14)$$

$$E_j = vK_j \qquad (3.16)$$

$$U_{jk} = U_{1k} + \sum_{m=2}^{j} Q_m \qquad (3.28)$$

$$C_{jk} = H_{jk} + S_{jk} \qquad (3.1)$$

$$H_{jk} = p_k (P_j + s_k a M_j) + s_k b E_j \qquad (3.8), (3.15), (3.12) \text{ and } (3.17)$$

$$p_k = (Vr_k + Wm_k)^{1/g} \qquad (3.13)$$

$$S_{jk} = Q_j + A_j F_{jk} \qquad (3.18)$$

$$F_{jk} = f_m + (f_M - f_m)\exp(-nU_{jk}/T_k) \qquad (3.24)$$

$$U_{mk} = \sum_{j=1}^{m} C_{jk} \qquad (3.2)$$

p_k cost-to-performance coefficient for architecture k

s_k the normalized s-measure for architecture k

a main-memory static storage ratio

b secondary-memory static storage ratio

r_k normalized r-measure for architecture k

m_k	normalized m-measure for architecture k
V	weighting factor for the r-measure
W	weighting factor for the m-measure
g	exponent of cost in the function relating performance to cost.
Q_j	expenditure for support software development in year j.
F_{jk}	amount of base (nominal) applications-software expenditure that should be used in determining the actual applications software cost in year j for architecture k.
f_m	minimum value F_{jk} can assume
f_M	maximum value F_{jk} can assume
h	coefficient relating support software availability to rate of decrease of applications software costs
T_k	dollar value of an ideal support software base for architecture k
D_{mk}	the nondiscounted cumulative cost over the years 1 through m for architecture k
D^*_{mk}	the discounted cumulative cost over the years 1 through m for architecture k
d_j	the discount factor for year j
w	factor derived from the annual discount rate
q	annual discount rate in percent
R_{jk}	the nondiscounted cumulative cost ratio of architecture k relative to architecture one for a period of j years.

$$D^*_{mk} = \sum_{J=1}^{m} C_{jk} d_j \qquad (3.3)$$

$$d_j = (w^{1-j} - w^{-j})/\ln(w) \qquad (3.5)$$

$$w = 1 + q/100 \qquad (3.4)$$

$$R_{jk} = D_{jk} / D_{j1} \qquad (3.6)$$

$$R^*_{jk} = D^*_{jk} / D^*_{j1} \qquad (3.7)$$

The parameters appearing in the above equations are briefly:

j	index of year (1=1978,.., 13=1990)
k	index of architecture (1:S/370, 2:PDP-11, 3:Interdata 8/32)
N_y	total number of years considered
N_a	total number of architectures
A_j	base (nominal) applications software expenditure
B_j	base (nominal) hardware expenditure
ρ	software-to-hardware ratio
K_j	nominal yearly processor cost
P_j	nominal yearly central processor expenditure
M_j	nominal yearly main memory expenditure
α	main-memory to processor ratio
u	processor-to-base hardware expenditure ratio
v	secondary memory-to-base hardware expenditure ratio
E_j	nominal yearly expenditure on secondary memory
U_{jk}	dollar value of available support software in year j for architecture k
Q_m	dollar expenditure for support software development in year m
C_{jk}	yearly architecture-dependent total cost
H_{jk}	yearly architecture-dependent total hardware cost
S_{jk}	yearly architecture-dependent total software cost
R^*_{jK}	the discounted cumulative cost ratio of architecture k relative to architecture one for a period of j years.

c. SENSITIVITY STUDIES

Figures 3-1, 3-2, 3-4 and 3-5 summarize the results of varying the software-to-hardware ratio (ρ = 1/8, 1/4, 1/2, 1, 2, 4) and the support-software expenditures (Q_j = 0, $1x10^6$, $2x10^6$, $4x10^6$, $8x10^6$). These variations constitute the first thirty cases of the sensitivity studies.

All of the sensitivity studies assume the discount factor, q, is ten percent (the value recommended by [AFR--69] and used in [SADPR74]).

Further assessing the model's sensitivity, we selectively perturbed individual input parameters about case number 18's (ρ=1 and Q_j=$2x10^6$) input data set to obtain twenty-nine additional input data sets. We chose the case 18 data set as a reference because, at this time, it appears to be the most reasonable of the first thirty data sets based on our current understanding of the characteristics of military embedded computer systems, the candidate architectures, and probable success of CFA. Tables 3-1 and 3-2 summarize the input data sets for cases 31 through 59. In these tables, heavy black lines set off the parameters that we perturbed from the reference values of case 18.

In order to simplify the computations, when perturbing the fraction of available support software in year 1, U_{1k}/T_k, we assumed the parameter that the applications software scaling parameter, k', remained constant at the value it had for the case 18 (reference) data set, rather than change it according to equations (3.22) and (3.23).

Sensitivity Studies

Case	Dev. Cycle		g	a	b	u	v	U_{11}/T_1	U_{12}/T_2	U_{13}/T_3	p	Q_j
31	5	0.65	1.5	0.8	0.2	0.5	0.1	0.697	0.474	0.320	1	2
32	10	0.65	1.5	0.8	0.2	0.5	0.1	0.697	0.474	0.320	1	2
33	7	0.50	1.5	0.8	0.2	0.5	0.1	0.697	0.474	0.320	1	2
34	7	0.80	1.5	0.8	0.2	0.5	0.1	0.697	0.474	0.320	1	2
35	7	0.65	1.0	0.8	0.2	0.5	0.1	0.697	0.474	0.320	1	2
36	7	0.65	2.0	0.8	0.2	0.5	0.1	0.697	0.474	0.320	1	2
37	7	0.65	1.5	0.6	0.2	0.5	0.1	0.697	0.474	0.320	1	2
38	7	0.65	1.5	0.9	0.2	0.5	0.1	0.697	0.474	0.320	1	2
39	7	0.65	1.5	0.8	0.1	0.5	0.1	0.697	0.474	0.320	1	2
40	7	0.65	1.5	0.8	0.3	0.5	0.1	0.697	0.474	0.320	1	2
41	7	0.65	1.5	0.8	0.2	0.4	0.1	0.697	0.474	0.320	1	2
42	7	0.65	1.5	0.8	0.2	0.6	0.1	0.697	0.474	0.320	1	2
43	7	0.65	1.5	0.8	0.2	0.5	0.0	0.697	0.474	0.320	1	2
44	7	0.65	1.5	0.8	0.2	0.5	0.2	0.697	0.474	0.320	1	2
45	7	0.65	1.5	0.8	0.2	0.5	0.1	0.600	0.474	0.320	1	2
46	7	0.65	1.5	0.8	0.2	0.5	0.1	0.800	0.474	0.320	1	2
47	7	0.65	1.5	0.8	0.2	0.5	0.1	0.697	0.400	0.320	1	2
48	7	0.65	1.5	0.8	0.2	0.5	0.1	0.697	0.600	0.320	1	2
49	7	0.65	1.5	0.8	0.2	0.5	0.1	0.697	0.474	0.200	1	2
50	7	0.65	1.5	0.8	0.2	0.5	0.1	0.697	0.474	0.400	1	2

Table 3-1

Sensitivity Studies (cont'd)

Case		s'_1	s'_2	s'_3	m'_1	m'_2	m'_3	r'_1	r'_2	r'_3
51	s_1 up 20%	1.450	0.868	0.718	1.266	0.928	0.850	1.292	0.938	0.825
52	s_2 up 20%	1.089	1.200	0.746	1.266	0.928	0.850	1.292	0.938	0.825
53	s_3 up 20%	1.117	0.925	0.993	1.266	0.928	0.850	1.292	0.938	0.825
54	m_1 up 20%	1.208	1.000	0.828	1.519	0.796	0.729	1.292	0.938	0.825
55	m_2 up 20%	1.208	1.000	0.828	1.155	1.114	0.775	1.292	0.938	0.825
56	m_3 up 20%	1.208	1.000	0.828	1.168	0.856	1.020	1.292	0.938	0.825
57	r_1 up 20%	1.208	1.000	0.828	1.266	0.928	0.850	1.550	0.800	0.704
58	r_2 up 20%	1.208	1.000	0.828	1.266	0.928	0.850	1.178	1.126	0.752
59	r_3 up 20%	1.208	1.000	0.828	1.266	0.928	0.850	1.196	0.869	0.990

Table 3-2

Despite this simplification, we believe the resulting perturbation is useful in assessing the effects of uncertainties in the support software availability. Also, when varying the s-measures in cases 51 through 53, we insisted that the sum of the perturbed s-measures, which we call s_1', s_2', and s_3' in Table 3-2, had to equal the sum of the case 18 s-measures (s_1 = 1.208, s_2 = 1.000, s_3 = 0.828) in order to preserve their relative normalization. In addition, we assumed that, for example in case 51, when the s-measure for architecture 1 moved up by 20%, i.e., $s_1' = 1.2\ s_1$, then s_2 and s_3 would have to move down by a common factor that would allow the sum to remain invariant. In particular, we insisted that, in this case,

$$s_2' = s_2 t \tag{3.29}$$

and

$$s_3' = s_3 t \tag{3.30}$$

where

$$t = (s_1 + s_2 + s_3 - s_1') / (s_2 + s_3) \tag{3.31}$$

Table 3-2 also shows the results of perturbing s_2, s_3, m_1, m_2, m_3, r_1, r_2, and r_3 in an analogous manner.

Figures 3-6 and 3-7 summarize the results of the sensitivity studies (for cases 31 through 59) for 1985 and 1990, respectively. The dotted lines in these figures are indicative of the discounted cumulative cost ratios for the reference data set (case 18), and the arrows show the amount and direction of movement from these values as the result of parameter perturbation. From these figures, we see uncertainties in the percentage of the ideal support-software base available in year 1 (U_{1k}/T_k), and uncertainties in u, the ratio of yearly processor expenditure to base hardware expenditure (K_j/B_j), can have significant impacts on the results.

Appendix A, Section 3.6, gives some of the input parameters and all of the resulting cumulative costs and cost ratios generated by model for cases 1 through 59.

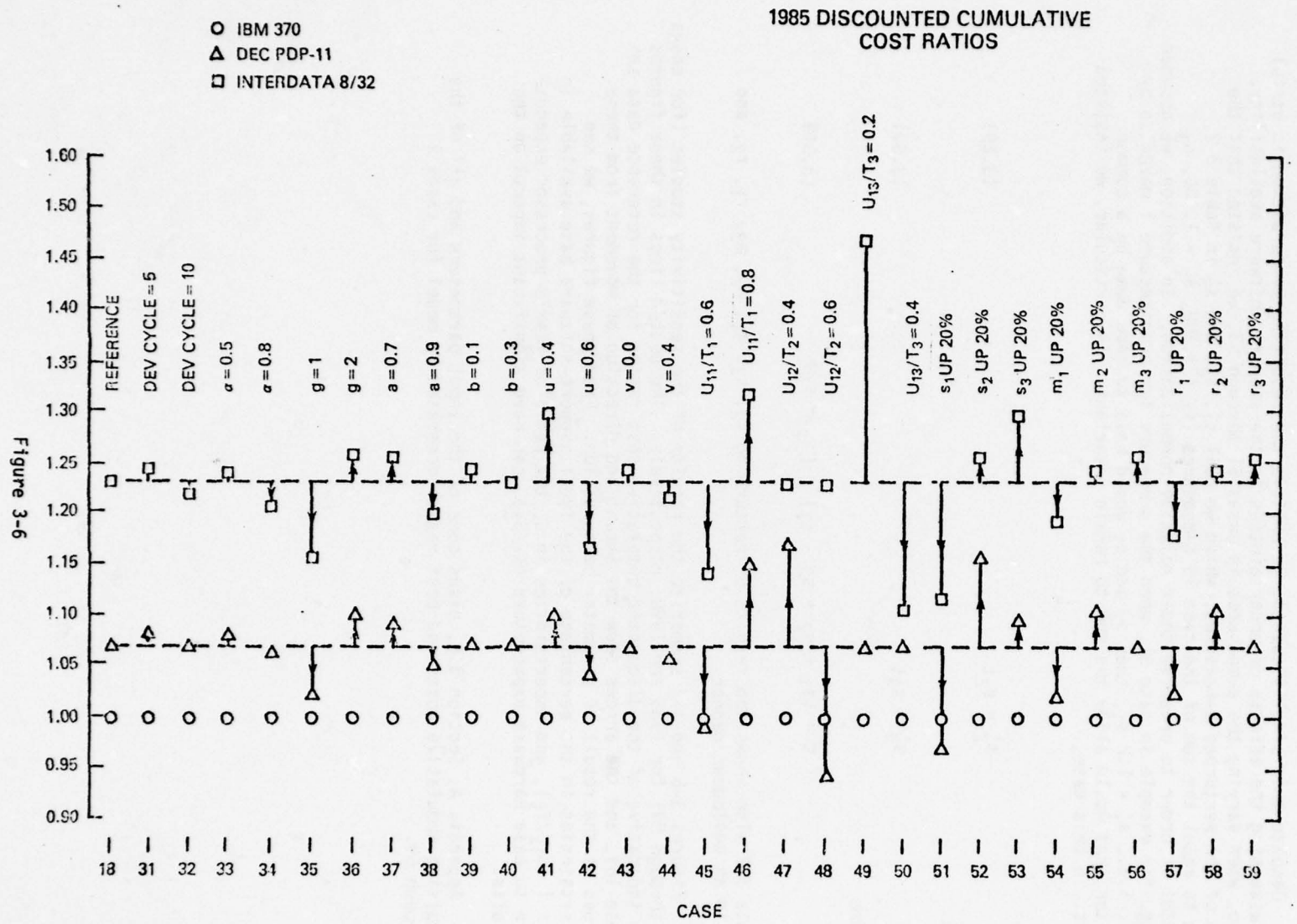

1985 DISCOUNTED CUMULATIVE COST RATIOS
IBM 370
DEC PDP-11
INTERDATA 8/32
1.60
1.50
1.45
1.40
1.35
1.30
1.25
1.20
1.15
1.10
1.05
1.00
0.95
0.90
REFERENCE
DEV CYCLE = 5
DEV CYCLE = 10
α = 0.5
α = 0.8
g = 1
g = 2
a = 0.7
a = 0.9
b = 0.1
b = 0.3
u = 0.4
u = 0.6
v = 0.0
v = 0.4
$U_{11}/T_1 = 0.6$
$U_{11}/T_1 = 0.8$
$U_{12}/T_2 = 0.4$
$U_{12}/T_2 = 0.6$
$U_{13}/T_3 = 0.2$
$U_{13}/T_3 = 0.4$
s_1 UP 20%
s_2 UP 20%
s_3 UP 20%
m_1 UP 20%
m_2 UP 20%
m_3 UP 20%
r_1 UP 20%
r_2 UP 20%
r_3 UP 20%
18 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59
CASE

Figure 3-6

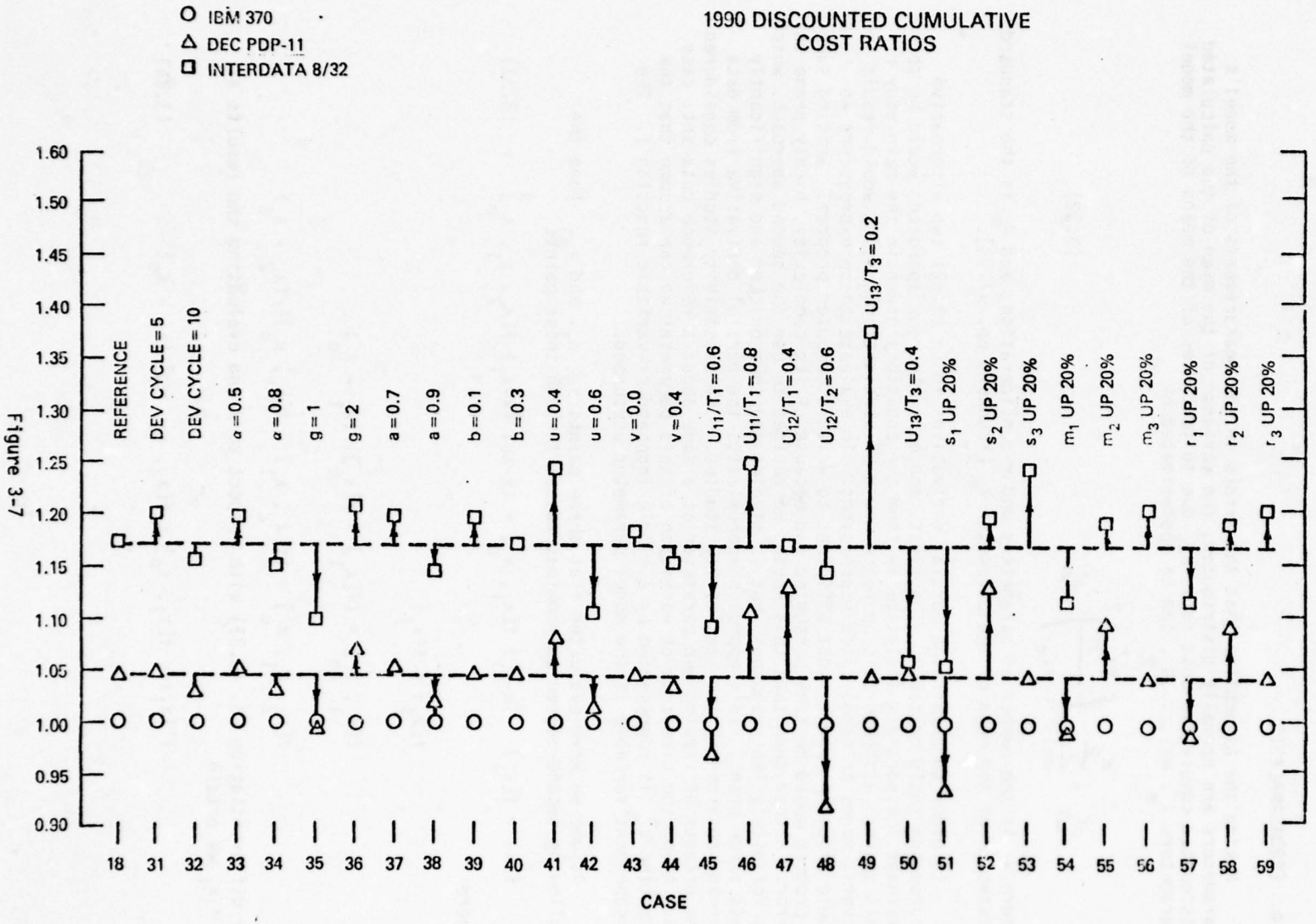

IBM 370
DEC PDP-11
INTERDATA 8/32
1990 DISCOUNTED CUMULATIVE COST RATIOS
1.60
1.50
1.45
1.40
1.35
1.30
1.25
1.20
1.15
1.10
1.05
1.00
0.95
0.90
REFERENCE
DEV CYCLE = 5
DEV CYCLE = 10
α = 0.5
α = 0.8
g = 1
g = 2
a = 0.7
a = 0.9
b = 0.1
b = 0.3
u = 0.4
u = 0.6
v = 0.0
v = 0.4
U11/T1 = 0.6
U11/T1 = 0.8
U12/T1 = 0.4
U12/T2 = 0.6
U13/T3 = 0.2
U13/T3 = 0.4
s1 UP 20%
s2 UP 20%
s3 UP 20%
m1 UP 20%
m2 UP 20%
m3 UP 20%
r1 UP 20%
r2 UP 20%
r3 UP 20%
18 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59
CASE

Figure 3-7

d. ERROR ANALYSIS

Making the assumption that the errors in the measurements of the model's parameters are normally distributed, the variance of the mean of the calculated discounted cumulative cost ratio R^*_{jk} due to variances of the means of the model parameters X_m, m=1, ...N_p, can be approximated by

$$\sigma^2_{jk} = \sum_{m=1}^{N_p} \left(\frac{\partial R^*_{jk}}{\partial X_m} \right)^2 \sigma^2_m \qquad (3.32)$$

where N_p is the number of parameters under consideration, and σ_m is the standard deviation of the mean of the parameter X_m [YounH62, pp. 97-98].

In order to obtain the partial derivatives in Eq (3.32) two alternative approaches could be taken. The first, and more rigorous approach, would be to evaluate the partials analytically from the equations given in the main body of this paper. Although this approach would be straightforward, it would result in several pages of complicated expressions. To evaluate these expressions we would probably find it most efficient to write a computer program. Writing such a program would be time consuming and because of its complexity, highly prone to error. Rather than take this route, we decided to use the second approach, which is definitely less rigorous, but is simpler and thus quicker and significantly less error prone. This approach approximates the partial derivative from data already obtained by the sensitivity studies. The sensitivity studies considered the effects of varying one parameter at a time about a reference data set, case 18. Along the direction of variation of this parameter we can assume that the function R^*_{jk} is represented by a single independent-variable function f. The independent variable is the model parameter perturbed.

Assume we have evaluated f at three points x_0, x_1, and x_2. Then the following second-degree polynominal passes through these points

$$f(x) = f[x_1] + (x-x_1)\, f[x_1, x_0] + (x-x_0)\,(x-x_1)\, f[x_2, x_1, x_0] \qquad (3.33)$$

where

$$f[x_1] = f(x_1)$$

$$f[x_1, x_0] = (f[x_1] - f[x_0])/(x_1 - x_0)$$

$$f[x_2, x_1, x_0] = (f[x_2, x_1] - f[x_1, x_0])/(x_2 - x_0)$$

By differentiating Eq. (3.33) with respect to x and evaluating the results at $x = x_1$ we obtain

$$f'(x_1) = f[x_1, x_0] + f[x_2, x_1, x_0]\,(x_1 - x_0) \qquad (3.34)$$

If $x_2 - x_1 = x_1 - x_0$, i.e. the function of f is sampled at equally spaced points, then Eq. (3.34) reduces to

$$f'(x_1) = (f(x_2) - f(x_0))/(x_2 - x_0) \qquad (3.35)$$

$$= f[x_2, x_0]$$

Assuming the value of x_1 was equal to the reference data points value, we use $f'(x_1)$ to approximate the partial of R^* with respect to x, evaluated at the reference data point.

For example, the value of u, the nominal yearly processor expenditure, used in the reference test case (case 18) was 0.5. Cases 41 and 42, however, also considered the effects of using u equal to 0.4 and 0.6. Table 3-3 shows the results for the year 1985.

	IBM	DEC	INT
u	R^*_{81}	R^*_{82}	R^*_{83}
0.4	1.00	1.10	1.30
0.5	1.00	1.07	1.23
0.6	1.00	1.04	1.17

Table 3-3

Since u was measured at equally spaced points, Eq (3.35) applies and we can approximate the derivatives of R^*_{8k} at the reference data point (case 18) by

$$\frac{\partial R^*_{81}}{\partial u} \simeq \frac{1.00 - 1.00}{0.6 - 0.4} = 0$$

$$\frac{\partial R^*_{82}}{\partial u} \simeq \frac{1.04 - 1.10}{0.6 - 0.4} = 0.3$$

$$\frac{\partial R^*_{83}}{\partial u} \simeq \frac{1.17 - 1.30}{0.6 - 0.4} = 0.65$$

Since architecture one is the reference architecture the partial derivative of R^*_{j1} with respect to any parameter will always be zero.

Table 3-4 summarizes the parameters varied in the sensitivity studies, their values (X_{18}) in the reference test case (case 18), and the resulting partial derivatives calculated using Eqs. (3.34) and (3.35) for the year 1985. Equation (3.35) was used to estimate all partials except those with respect to ρ and Q, which were obtained using Eq. (3.34). No calculations were made for the parameters B_1 through B_{13} because these parameters were not varied in the sensitivity studies. As mentioned earlier, however, these parameters just about completely factor out of the equations for the cumulative cost ratios and thus the effects of their errors are believed to be relatively insignificant.

m	Corresponding Model Parameter	Value X_m	$\partial R^{*DEC}_{82} / \partial X_m$	$\partial R^{*INT}_{83} / \partial X_m$
1	u	0.5	-0.30	-0.65
2	α	0.65	-0.07	-0.10
3	v	0.1	-0.05	-0.10
4	g	1.5	+0.08	+0.10
5	a	0.8	-0.20	-0.30
6	b	0.2	0.00	-0.05
7	s_1	1.208	-0.42	-0.41
8	s_2	1.000	+0.45	+0.15
9	s_3	0.828	+0.06	+0.42
10	m_1	1.266	-0.20	-0.20
11	m_2	0.928	+0.22	+0.05
12	m_3	0.850	0.00	+0.18
13	r_1	1.292	-0.19	-0.19
14	r_2	0.938	+0.21	+0.05
15	r_3	0.825	+0.00	+0.18
16	U_{11}/T_1	0.697	+0.80	+0.90
17	U_{12}/T_2	0.474	-1.16	+0.00
18	U_{13}/T_3	0.320	0.00	-1.80
19	ρ	1	+0.20	+0.38
20	Q_2-Q_{13}	2×10^6	$-.04\times10^{-6}$	$-.08\times10^{-6}$
21	B_1	7.14×10^6	not calculated	not calculated
22	B_2	14.3×10^6	"	"
23	B_3	21.4×10^6	"	"
24	B_4	28.6×10^6	"	"
25	B_5	37.5×10^6	"	"
26	B_6	42.5×10^6	"	"
27	B_7 - B_{13}	50.0×10^6	"	"

Table 3-4

Digital Equipment Corp. PDP-11

m	Model Parameter	Estimated Value	Estimated σ_m	σ_m^2	$\partial^2 R_{82}$	$\partial^2 R_{82}\sigma_m^2$
1	u	0.50	0.10	0.0100	0.090	0.000900
2	α	0.65	0.15	0.0225	0.0049	0.000110
3	v	0.10	0.05	0.0025	0.0025	0.000006
4	g	1.50	0.50	0.2500	0.0064	0.001600
5	a	0.80	0.10	0.0100	0.0400	0.000400
6	b	0.20	0.10	0.0100	0.0000	0.000000
7	s_1	1.208	0.24	0.0576	0.1764	0.010161
8	s_2	1.000	0.20	0.0400	0.2025	0.008100
9	s_3	0.828	0.16	0.0256	0.0036	0.000092
10	m_1	1.266	0.27	0.0729	0.0400	0.002916
11	m_2	0.928	0.20	0.0400	0.0484	0.001936
12	m_3	0.850	0.18	0.0324	0.0000	0.000000
13	r_1	1.292	0.28	0.0784	0.0361	0.000092
14	r_2	0.938	0.20	0.0400	0.0441	0.001764
15	r_3	0.825	0.18	0.0324	0.0000	0.000000
16	U_{11}/T_1	0.697	0.15	0.0225	0.6400	0.000466
17	U_{12}/T_1	0.474	0.10	0.0100	1.3456	0.013456
18	U_{13}/T_3	0.320	0.07	0.0049	0.0000	0.000000
19	ρ	1	0	0	0.0400	0.000000
20	Q_2-Q_{13}	2×10^6	0	0	1.6×10^{-15}	0.000000
21	B_1	7.14×10^6	0	0	nc	nc
22	B_2	14.3×10^6	0	0	nc	nc
23	B_3	21.4×10^6	0	0	nc	nc
24	B_4	28.6×10^6	0	0	nc	nc
25	B_5	37.5×10^6	0	0	nc	nc
26	B_6	42.5×10^6	0	0	nc	nc
27	B_7 - B_{13}	50.0×10^6	0	0	nc	nc
					Total = σ_{82}^2 =	0.041999

nc - not calculated

σ_{82} = 0.205

Table 3-5

INTERDATA 8/32

m	Model Parameter	Estimated Value	Estimated σ_m	σ_m^2	$\partial^2 R_{83}$	$\partial^2 R_{83} \sigma_m$
1	u	0.50	0.10	0.0100	0.4225	0.004225
2	α	0.65	0.15	0.0225	0.0100	0.000225
3	v	0.10	0.05	0.0025	0.0100	0.000025
4	g	1.50	0.50	0.2500	0.0100	0.002500
5	a	0.80	0.10	0.0100	0.0900	0.000900
6	b	0.20	0.10	0.0100	0.0025	0.000025
7	s_1	1.208	0.24	0.0576	0.1681	0.009682
8	s_2	1.000	0.20	0.0400	0.0225	0.000900
9	s_3	0.828	0.16	0.0256	0.1764	0.004516
10	m_1	1.266	0.27	0.0729	0.0400	0.002916
11	m_2	0.928	0.20	0.0400	0.0025	0.000100
12	m_3	0.850	0.18	0.0324	0.0324	0.001050
13	r_1	1.292	0.28	0.0784	0.0361	0.002830
14	r_2	0.938	0.20	0.0400	0.0025	0.000100
15	r_3	0.825	0.18	0.0324	0.0324	0.001050
16	U_{11}/T_1	0.697	0.15	0.0225	0.8100	0.018225
17	U_{12}/T_2	0.474	0.10	0.0100	0.0000	0.000000
18	U_{13}/T_3	0.320	0.07	0.0049	3.2400	0.015876
19	ρ	1	0	0	0.1444	0
20	Q_2-Q_{13}	2×10^6	0	0	6.4×10^{-15}	0
21	B_1	7.14×10^6	0	0	nc	0
22	B_2	14.3×10^6	0	0	nc	0
23	B_3	21.4×10^6	0	0	nc	0
24	B_4	28.6×10^6	0	0	nc	0
25	B_5	37.5×10^6	0	0	nc	0
26	B_6	42.5×10^6	0	0	nc	0
27	B_7 - B_{13}	50.0×10^6	0	0	nc	0

Total = σ_{83}^2 = 0.065145

nc - not calculated

σ_{83} = 0.225

Table 3-6

Table 3-5 and 3-6 explicitly show the evaluation of Eq (3.38). They give the estimated value of each model parameter as used in the reference test case (case 18). They also give the estimated standard deviation (σ_m) of the mean of each parameter. These standard deviations were obtained by the method of "educated guess." It should be noted that the standard deviations for ρ and Q_j were assumed to be zero. This is not because they are actually zero (in fact, they are quite large) but because we desired to obtain an estimate of the standard deviation of the point (ρ = 1) for Figure 3-1. This figure assumes Q_j and ρ are known exactly. From the partials given in Tables 3-4, 3-5 and 3-6 we see, however, that if the errors in Q_j and ρ were included in the calculations they would significantly increase the resulting value of σ_{jk}.

The results of these calculations indicate that the uncertainties in the model's major results are quite large. Table 3-7 summarizes the findings for a software-to-hardware ratio of one (ρ = 1) and support-software expenditures of two million dollars per year.

	k	R^*_{8k}	σ_{8k}
IBM	1	1.00	0.000
DEC	2	1.06	0.205
INT	3	1.22	0.255

Table 3-7

These results imply that because of uncertainties in our input data we cannot really resolve the question of which architecture is the most cost effective for this software-to-hardware ratio by using the top-down model. As a result, irreducibles probably should play a major role in the final decision.

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f. APPENDIX A - SUPPORTING DATA

This appendix gives, in tabular form, some of the input parameters and all of the resulting 1985 and 1990 cumulative costs and cost ratios generated by the model for Cases 1 through 59. Its contents include:

Table		
3-A.1	Cases 1-30	1985 and 1990 Cumulative Costs
3-A.2	Cases 1-30	1985 and 1990 Cumulative Cost Ratios
3-A.3	Case 3	ρ=1/8, Detailed Data and Results
3-A.4	Case 8	ρ=1/4, Detailed Data and Results
3-A.5	Case 13	ρ=1/2, Detailed Data and Results
3-A.6	Case 18	ρ=1, Detailed Data and Results
3-A.7	Case 23	ρ=2, Detailed Data and Results
3-A.8	Case 28	ρ=4, Detailed Data and Results
3-A.9	Cases 31-59	1985 and 1990 Cumulative Costs
3-A.10	Cases 31-59	1985 and 1990 Cumulative Cost Ratios

Table 3-A.2 follows from the data in Table A.1. Figures 3-1, 3-2, 3-4 and 3-5 graphically summarize the information in Table 3-A.2.

Tables 3-A.3 through 3-A.8 show detailed input data and results for Cases 3, 8, 13, 18, 23 and 28. These correspond to $Q_j=2\times10^6$, j=2, ...13, and ρ=1/8, 1/4, 1/2, 1, 2 and 4. In these tables, the values in row 1 are A_j, j=1, ...13. Row 2 shows B_j, j=1, ...13. Rows 2, 3, 4 show the total yearly software costs (S_{jk}) given by equation (3-18), where k=1 means IBM, k=2 means DEC, and k=3 means Interdata. Rows 6 through 8 give the yearly hardware costs (H_{jk}) of equation (3.8). Rows 9 through 11 give the total nondiscounted cumulative costs, as obtained from equation (3.2). Rows 12 through 14 give the total nondiscounted cumulative cost ratios, R_{jk}, of equation (3.6). Rows 15 through 20 give the corresponding discounted costs and ratios of equations (3.3) and (3.7). Row 21 gives the discount factors, d_j, obtained by applying equation (3.5) for a discount rate (q) of 10%, the value recommended in [AFR---69].

Tables 3-A.9 and 3-A.10 provide the (nondiscounted and discounted) cumulative costs and cost ratios (for 1985 and 1990, cases 31-59). Figures 3-6 and 3-7 graphically summarize the data in Table 3-A.10.

Case	ρ	$Q_j, j=2,\ldots 13$ ($Mil)	Ratios of Total Non-Discounted Cumulative Cost, R_{8k} 1985			Ratios of Total Discounted Cumulative Cost R^*_{8k} 1985			Ratios of Total Non-Discounted Cumulative Cost, R_{13k} 1990			Ratios of Total Discounted Cumulative Cost, R^*_{13k} 1990		
			IBM	DEC	INT	IBM	DEC	INT	IBM	DEC	INT	IBM	DEC	INT
1	1/8	0	1.00	0.830	0.789	1.00	0.827	0.791	1.00	0.825	0.790	1.00	0.824	0.789
2	1/8	1	1.00	0.811	0.766	1.00	0.823	0.775	1.00	0.808	0.750	1.00	0.814	0.762
3	1/8	2	1.00	0.810	0.754	1.00	0.811	0.756	1.00	0.796	0.728	1.00	0.801	0.739
4	1/8	4	1.00	0.810	0.741	1.00	0.809	0.745	1.00	0.791	0.712	1.00	0.800	0.724
5	1/8	8	1.00	0.817	0.746	1.00	0.824	0.750	1.00	0.803	0.722	1.00	0.812	0.734
6	1/4	0	1.00	0.902	0.933	1.00	0.908	0.933	1.00	0.904	0.935	1.00	0.906	0.932
7	1/4	1	1.00	0.880	0.885	1.00	0.884	0.892	1.00	0.864	0.859	1.00	0.873	0.868
8	1/4	2	1.00	0.861	0.845	1.00	0.869	0.861	1.00	0.842	0.810	1.00	0.852	0.825
9	1/4	4	1.00	0.840	0.805	1.00	0.850	0.819	1.00	0.818	0.760	1.00	0.830	0.778
10	1/4	8	1.00	0.836	0.777	1.00	0.843	0.793	1.00	0.815	0.743	1.00	0.826	0.760
11	1/2	0	1.00	1.02	1.14	1.00	1.02	1.14	1.00	1.02	1.14	1.00	1.02	1.14
12	1/2	1	1.00	0.982	1.07	1.00	0.986	1.08	1.00	0.959	1.03	1.00	0.968	1.04
13	1/2	2	1.00	0.946	1.00	1.00	0.957	1.01	1.00	0.915	0.945	1.00	0.930	0.972
14	1/2	4	1.00	0.905	0.918	1.00	0.915	0.937	1.00	0.862	0.843	1.00	0.882	0.877
15	1/2	8	1.00	0.867	0.837	1.00	0.880	0.853	1.00	0.837	0.782	1.00	0.853	0.809
16	1	0	1.00	1.16	1.40	1.00	1.16	1.40	1.00	1.16	1.40	1.00	1.16	1.39
17	1	1	1.00	1.11	1.30	1.00	1.11	1.31	1.00	1.08	1.26	1.00	1.09	1.27
18	1	2	1.00	1.06	1.22	1.00	1.07	1.23	1.00	1.02	1.14	1.00	1.04	1.17
19	1	4	1.00	0.992	1.08	1.00	1.00	1.10	1.00	0.935	0.977	1.00	0.964	1.03
20	1	8	1.00	0.919	0.935	1.00	0.935	0.964	1.00	0.873	0.848	1.00	0.899	0.895
21	2	0	1.00	1.29	1.64	1.00	1.29	1.64	1.00	1.29	1.64	1.00	1.29	1.64
22	2	1	1.00	1.24	1.25	1.00	1.24	1.55	1.00	1.21	1.50	1.00	1.22	1.51
23	2	2	1.00	1.19	1.46	1.00	1.20	1.47	1.00	1.14	1.37	1.00	1.16	1.40
24	2	4	1.00	1.10	1.29	1.00	1.12	1.32	1.00	1.04	1.16	1.00	1.07	1.22
25	2	8	1.00	0.997	1.08	1.00	1.02	1.12	1.00	0.931	0.953	1.00	0.969	1.02
26	4	0	1.00	1.39	1.83	1.00	1.39	1.83	1.00	1.39	1.82	1.00	1.39	1.82
27	4	1	1.00	1.35	1.75	1.00	1.35	1.75	1.00	1.33	1.70	1.00	1.34	1.72
28	4	2	1.00	1.30	1.66	1.00	1.31	1.68	1.00	1.26	1.58	1.00	1.28	1.62
29	4	4	1.00	1.22	1.51	1.00	1.24	1.54	1.00	1.14	1.36	1.00	1.18	1.43
30	4	8	1.00	1.09	1.26	1.00	1.12	1.31	1.00	1.01	1.08	1.00	1.06	1.18

Table 3-A.1

Case	ρ	$Q_j, j=2,\ldots 13$ ($Mil)	Total Non-Discounted Cumulative Cost ($Mil), D_{8k} 1985			Total Discounted Cumulative Cost ($Mil), D^*_{8k} 1985			Total Non-Discounted Cumulative Cost ($Mil), D_{13k} 1990			Total Discounted Cumulative Cost ($Mil), D^*_{13k} 1990		
			IBM	DEC	INT	IBM	DEC	INT	IBM	DEC	INT	IBM	DEC	INT
1	1/8	0	171	142	135	107	88.5	84.6	343	283	271	171	141	135
2	1/8	1	175	142	134	109	89.7	84.5	344	278	258	172	140	131
3	1/8	2	179	145	135	113	91.6	85.4	349	278	254	176	141	130
4	1/8	4	189	153	140	120	97.1	89.4	364	288	259	185	148	134
5	1/8	8	213	174	159	136	112	102	406	326	293	207	168	152
6	1/4	0	193	174	180	120	109	112	385	348	360	192	174	179
7	1/4	1	192	169	170	121	107	108	376	325	323	189	165	164
8	1/4	2	194	167	164	122	106	105	373	314	302	189	161	156
9	1/4	4	200	168	161	127	108	104	380	311	289	194	161	151
10	1/4	8	220	184	171	140	118	111	416	339	309	213	176	162
11	1/2	0	235	240	269	147	150	168	470	479	538	234	239	268
12	1/2	1	227	223	243	143	141	154	439	421	452	222	215	232
13	1/2	2	223	211	224	141	135	143	422	386	399	215	200	209
14	1/2	4	221	200	203	141	129	132	413	356	348	212	187	186
15	1/2	8	233	202	195	150	132	128	435	364	340	225	192	182
16	1	0	320	371	447	200	232	280	640	741	894	319	369	445
17	1	1	298	330	388	188	209	246	566	612	711	288	314	366
18	1	2	282	300	344	179	192	221	520	531	592	268	278	314
19	1	4	265	263	287	170	171	188	478	447	467	249	240	256
20	1	8	261	240	244	169	158	163	474	414	402	248	223	222
21	2	0	490	632	803	306	396	502	980	1265	1606	488	630	800
22	2	1	439	544	678	278	345	430	820	995	1227	420	514	636
23	2	2	400	477	582	256	307	376	716	820	979	374	435	525
24	2	4	352	389	455	228	256	301	607	629	705	323	346	395
25	2	8	316	315	340	207	211	232	553	515	527	295	286	301
26	4	0	830	1156	1516	519	723	948	1661	2312	3031	828	1152	1510
27	4	1	720	972	1258	456	617	800	1327	1760	2261	683	912	1175
28	4	2	637	831	1060	408	536	685	1108	1397	1753	585	749	946
29	4	4	525	642	791	343	425	527	866	992	1181	471	557	674
30	4	8	425	465	534	283	317	370	710	716	776	389	411	460

Table 3-A.2

Year Case 3

	1	2	3	4	5	6	7	8	9	10	11	12	13	
	78	79	80	81	82	83	84	85	86	87	88	89	90	Row
Base Appl. Sftwe Exp.	0.893	1.78	2.68	3.57	4.46	5.36	6.25	6.25	6.25	6.25	6.25	6.25	6.25	1
Base Hdwe Exp. ($Mil)	7.14	14.3	21.4	28.6	35.7	42.8	50.0	50.0	50.0	50.0	50.0	50.0	50.0	2
Total Yearly Software														
(1) IBM ($Mil)	0.607	3.12	3.54	3.89	4.18	4.42	4.61	4.41	4.24	4.08	3.93	3.80	3.68	3
(2) DEC	9.35	3.71	4.34	4.86	5.28	5.61	5.86	5.54	5.26	5.01	4.77	4.56	4.37	4
(3) INT	1.27	4.32	5.18	5.87	6.42	6.85	7.18	6.75	6.35	6.00	5.67	5.38	5.11	5
Total Yearly Hardware														
(1) IBM ($Mil)	4.26	8.59	12.8	17.2	21.4	25.7	30.0	30.0	30.0	30.0	30.0	30.0	30.0	6
(2) DEC	3.09	6.22	9.32	12.4	15.5	18.6	21.8	21.8	21.8	21.8	21.8	21.8	21.8	7
(3) INT	2.58	5.20	7.77	10.4	13.0	15.6	18.2	18.2	18.2	18.2	18.2	18.2	18.2	8
Total Non-Discounted Cumulative Cost														
(1) IBM ($Mil)	4.87	16.6	33.0	54.0	79.6	110	144	179	213	247	281	315	349	9
(2) DEC	4.03	14.0	27.6	44.9	65.8	90.0	118	145	172	199	225	252	278	10
(3) INT	3.85	13.4	26.3	42.6	62.0	84.4	110	135	159	183	207	231	254	11
Total Non-Discounted Cum. Cost Ratios														
(1) IBM	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	12
(2) DEC	0.827	0.843	0.847	0.831	0.27	0.818	0.819	0.810	0.808	0.806	0.801	0.800	0.796	13
(3) INT	0.790	0.807	0.807	0.789	0.779	0.767	0.764	0.754	0.746	0.741	0.737	0.733	0.728	14
Total Discounted Cumulative Cost														
(1) IBM ($Mil)	4.67	14.8	27.7	42.8	59.5	77.3	95.8	113	128	142	154	166	176	15
(2) DEC	3.84	12.4	23.2	36.5	49.2	63.6	78.3	91.6	104	114	124	133	141	16
(3) INT	3.67	11.9	22.1	33.8	46.4	59.7	73.2	85.4	96.3	106	115	123	130	17
Total Discounted Cum. Ratios														
(1) IBM	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	18
(2) DEC	0.822	0.838	0.838	0.832	0.827	0.823	0.817	0.811	0.812	0.803	0.805	0.801	0.801	19
(3) INT	0.786	0.804	0.798	0.790	0.780	0.772	0.764	0.756	0.752	0.746	0.747	0.741	0.739	20
Discount Factor (10%)	0.954	0.867	0.788	0.717	0.652	0.592	0.538	0.489	0.445	0.405	0.368	0.334	0.304	21

$\rho = 1/8$ $Q_j = 2 \times 10^6$ Dev. Cycle = 7 $\alpha = 0.65$ $g = 1.5$ $a = 0.8$ $b = 0.2$

$s_1, s_2, s_3 = 1.208, 1.000, 0.828$ $m_1, m_2, m_3 = 1.266, 0.928, 0.850$ $r_1, r_2, r_3 = 1.292, 0.938, 0.825$

Table 3-A.3

	Year													
	1	2	3	4	5	6	7	8	9	10	11	12	13	
	78	79	80	81	82	83	84	85	86	87	88	89	90	Row
Base Appl. Sftwe Exp.	1.78	3.57	5.36	7.14	8.93	10.7	12.5	12.5	12.5	12.5	12.5	12 5	12.5	1
Base Hdwe Exp. ($Mil)	7.14	14.3	21.4	28.6	35.7	42.8	50.0	50.0	50.0	50.0	50.0	50.0	50.0	2
Total Yearly Software														
(1) IBM ($Mil)	1.22	4.23	5.08	5.78	6.36	6.83	7.21	6.82	6.47	6.16	5.86	5.60	5.36	3
(2) DEC	1.87	5.42	6.69	7.72	8.55	9.21	9.72	9.10	8.53	8.01	7.54	7.12	6.74	4
(3) INT	2.54	6.64	8.36	9.74	10.8	11.7	12.4	11.5	10.7	9.99	9.34	8.75	8.22	5
Total Yearly Hardware														
(1) IBM ($Mil)	4.26	8.59	12.8	17.2	21.4	25.7	30.0	30.0	30.0	30.0	30.0	30.0	30.0	6
(2) DEC	3.09	6.22	9.32	12.4	15.5	18.6	21.8	21.8	21.8	21.8	21.8	21.8	21.8	7
(3) INT	2.58	5.20	7.77	10.4	13.0	15.6	18.2	18.2	18.2	18.2	18.2	18.2	18.2	8
Total Non-Discounted Cumulative Cost														
(1) IBM ($Mil)	5.48	18.3	36.2	59.2	87.0	120	157	194	230	266	302	338	373	9
(2) DEC	4.96	16.6	32.6	52.8	76.9	105	136	167	197	227	256	285	314	10
(3) INT	5.12	17.0	33.1	53.2	77.0	104	135	164	193	222	249	276	302	11
Total Non-Discounted Cum. Cost Ratios														
(1) IBM	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	12
(2) DEC	0.905	0.907	0.900	0.892	0.884	0.875	0.866	0.861	0.856	0.853	0.848	0.843	0.842	13
(3) INT	0.934	0.929	0.914	0.899	0.885	0.867	0.860	0.845	0.839	0.834	0.824	0.816	0.810	14
Total Discounted Cumulative Cost														
(1) IBM ($Mil)	5.23	16.3	30.5	46.9	65.0	84.3	104	122	138	153	166	178	189	15
(2) DEC	4.73	14.8	27.4	41.9	57.6	74.1	90.9	106	120	132	143	152	161	16
(3) INT	4.89	15.2	27.9	42.3	57.8	74.0	90.2	105	118	129	139	148	156	17
Total Discounted Cum. Ratios														
(1) IBM	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	18
(2) DEC	0.904	0.908	0.898	0.893	0.886	0.879	0.874	0.869	0.870	0.863	0.861	0.854	0.852	19
(3) INT	0.935	0.932	0.914	0.902	0.889	0.878	0.867	0.861	0.855	0.843	0.837	0.831	0.825	20
Discount Factor (10%)	0.954	0.867	0.788	0.717	0.652	0.592	0.538	0.489	0.445	0.405	0.368	0.334	0.304	21

Case 8

$\rho = 1/4$ $Q_j = 2 \times 10^6$ Dev. Cycle = 7 $\alpha = 0.65$ $g = 1.5$ $a = 0.8$ $b = 0.2$

$s_1, s_2, s_3 = 1.208, 1.000, 0.828$ $m_1, m_2, m_3 = 1.266, 0.928, 0.850$ $r_1, r_2, r_3 = 1.292, 0.938, 0.825$

Table 3-A.4

Case 13

	Year 1	2	3	4	5	6	7	8	9	10	11	12	13	
	78	79	80	81	82	83	84	85	86	87	88	89	90	Row
Base Appl. Sftwe Exp.	3.57	7.14	10.7	14.3	17.9	21.4	25.0	25.0	25.0	25.0	25.0	25.0	25.0	1
Base Hdwe Exp. ($Mil)	7.14	14.3	21.4	28.6	35.7	42.8	50.0	50.0	50.0	50.0	50.0	50.0	50.0	2
Total Yearly Software														
(1) IBM ($Mil)	2.43	6.47	8.16	9.57	10.7	11.7	12.4	11.6	10.9	10.3	9.73	9.20	8.73	3
(2) DEC	3.74	8.84	11.4	13.4	15.1	16.4	17.4	16.2	15.1	14.0	13.1	12.2	11.5	4
(3) INT	5.09	11.3	14.7	17.5	19.7	21.4	22.7	21.0	19.4	18.0	16.7	15.5	14.4	5
Total Yearly Hardware														
(1) IBM ($Mil)	4.26	8.59	12.8	17.2	21.4	25.7	30.0	30.0	30.0	30.0	30.0	30.0	30.0	6
(2) DEC	3.09	6.22	9.32	12.4	15.5	18.6	21.8	21.8	21.8	21.8	21.8	21.8	21.8	7
(3) INT	2.58	5.20	7.77	10.4	13.0	15.6	18.2	18.2	18.2	18.2	18.2	18.2	18.2	8
Total Non-Discounted Cumulative Cost														
(1) IBM ($Mil)	6.69	21.8	42.8	69.5	102	139	182	223	264	304	344	383	422	9
(2) DEC	6.83	21.9	42.6	68.5	99.1	134	173	211	248	284	319	353	386	10
(3) INT	7.67	24.2	46.6	74.5	107	144	185	224	262	298	333	366	399	11
Total Non-Discounted Cum. Cost Ratios														
(1) IBM	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	12
(2) DEC	1.02	1.00	0.995	0.986	0.972	0.964	0.950	0.946	0.939	0.934	0.927	0.922	0.915	13
(3) INT	1.15	1.11	1.09	1.07	1.05	1.04	1.02	1.00	0.992	0.980	0.968	0.956	0.945	14
Total Discounted Cumulative Cost														
(1) IBM ($Mil)	6.38	19.4	36.0	55.2	76.1	98.2	121	141	160	176	190	204	215	15
(2) DEC	6.52	19.6	35.9	54.4	74.4	95.2	116	135	151	166	178	190	200	16
(3) INT	7.32	21.6	39.3	59.3	80.6	102	124	143	160	174	188	199	209	17
Total Discounted Cum. Ratios														
(1) IBM	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	18
(2) DEC	1.02	1.01	0.997	0.986	0.978	0.969	0.959	0.957	0.944	0.943	0.937	0.931	0.930	19
(3) INT	1.15	1.11	1.09	1.07	1.06	1.04	1.02	1.01	1.00	0.989	0.989	0.975	0.972	20
Discount Factor (10%)	0.954	0.867	0.788	0.717	0.652	0.592	0.538	0.489	0.445	0.405	0.368	0.334	0.304	21

$\rho = 1/2$ $Q_j = 2 \times 10^6$ Dev. Cycle = 7 $\alpha = 0.65$ $g = 1.5$ $a = 0.8$ $b = 0.2$

$s_1, s_2, s_3 = 1.208, 1.000, 0.828$ $m_1, m_2, m_3 = 1.266, 0.928, 0.850$ $r_1, r_2, r_3 = 1.292, 0.938, 0.825$

Table 3-A.5

Case 18 (Reference)

	Year 1	2	3	4	5	6	7	8	9	10	11	12	13	
	78	79	80	81	82	83	84	85	86	87	88	89	90	Row
Base Appl. Sftwe Exp.	7.14	14.3	21.4	28.6	35.7	42.8	50.0	50.0	50.0	50.0	50.0	50.0	50.0	1
Base Hdwe Exp. ($Mil)	7.14	14.3	21.4	28.6	35.7	42.8	50.0	50.0	50.0	50.0	50.0	50.0	50.0	2
Total Yearly Software														
(1) IBM ($Mil)	4.86	10.9	14.3	17.1	19.4	21.3	22.8	21.3	19.9	18.6	17.5	16.4	15.4	3
(2) DEC	7.48	15.7	20.8	24.9	28.2	30.8	32.9	30.4	28.1	26.0	24.2	22.5	21.0	4
(3) INT	10.2	20.6	27.4	33.0	37.4	40.8	43.5	40.0	36.8	34.0	31.4	29.0	26.9	5
Total Yearly Hardware														
(1) IBM ($Mil)	4.26	8.59	12.8	17.2	21.4	25.7	30.0	30.0	30.0	30.0	30.0	30.0	30.0	6
(2) DEC	3.09	6.22	9.32	12.4	15.5	18.6	21.8	21.8	21.8	21.8	21.8	21.8	21.8	7
(3) INT	2.58	5.20	7.77	10.4	13.0	15.6	18.2	18.2	18.2	18.2	18.2	18.2	18.2	8
Total Non-Discounted Cumulative Cost														
(1) IBM ($Mil)	9.12	28.6	55.8	90.1	131	178	231	282	332	381	428	475	520	9
(2) DEC	10.6	32.5	62.6	99.9	144	193	248	300	350	398	444	488	531	10
(3) INT	12.8	38.5	73.7	117	167	224	285	344	399	451	500	547	592	11
Total Non-Discounted Cum. Cost Ratios														
(1) IBM	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	12
(2) DEC	1.16	1.14	1.12	1.11	1.10	1.08	1.07	1.06	1.05	1.04	1.04	1.03	1.02	13
(3) INT	1.40	1.35	1.32	1.30	1.27	1.26	1.23	1.22	1.20	1.18	1.17	1.15	1.14	14
Total Discounted Cumulative Cost														
(1) IBM ($Mil)	8.70	25.6	47.0	71.6	98.3	126	154	179	202	221	239	254	268	15
(2) DEC	10.1	29.1	52.8	79.6	108	137	166	192	214	234	250	265	278	16
(3) INT	12.2	34.5	62.2	93.3	126	160	192	221	245	266	284	300	314	17
Total Discounted Cum. Ratios														
(1) IBM	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	18
(2) DEC	1.16	1.14	1.12	1.11	1.10	1.09	1.08	1.07	1.06	1.06	1.05	1.04	1.04	19
(3) INT	1.40	1.35	1.32	1.30	1.28	1.26	1.25	1.23	1.21	1.20	1.19	1.18	1.17	20
Discount Factor (10%)	0.954	0.867	0.788	0.717	0.652	0.592	0.538	0.489	0.445	0.405	0.368	0.334	0.304	21

$\rho = 1$ $Q_j = 2 \times 10^6$ Dev. Cycle = 7 $\alpha = 0.65$ $g = 1.5$ $a = 0.8$ $b = 0.2$

$s_1, s_2, s_3 = 1.208, 1.000, 0.828$ $m_1, m_2, m_3 = 1.266, 0.928, 0.850$ $r_1, r_2, r_3 = 1.292, 0.938, 0.825$

Table 3-A.6

Year Case 23

	1	2	3	4	5	6	7	8	9	10	11	12	13	
	78	79	80	81	82	83	84	85	86	87	88	89	90	Row
Base Appl. Sftwe Exp.	14.3	28.6	42.9	57.1	71.4	85.7	100	100	100	100	1.00	1.00	1.00	1
Base Hdwe Exp. ($Mil)	7.14	14.3	21.4	28.6	35.7	42.8	50.0	50.0	50.0	50.0	50.0	50.0	50.0	2
Total Yearly Software														
(1) IBM ($Mil)	9.72	19.9	26.6	32.3	36.9	40.7	43.7	40.6	37.8	35.2	32.9	30.8	28.9	3
(2) DEC	15.0	29.4	39.5	47.8	54.4	59.7	63.8	58.8	54.2	50.1	46.4	43.0	39.9	4
(3) INT	20.4	39.1	52.8	64.0	72.8	79.7	84.9	78.0	71.7	65.9	60.7	56.0	51.7	5
Total Yearly Hardware														
(1) IBM ($Mil)	4.26	8.59	12.8	17.2	21.4	25.7	30.0	30.0	30.0	30.0	30.0	30.0	30.0	6
(2) DEC	3.09	6.22	9.32	12.4	15.5	18.6	21.8	21.8	21.8	21.8	21.8	21.8	21.8	7
(3) INT	2.58	5.20	7.77	10.4	13.0	15.6	18.2	18.2	18.2	18.2	18.2	18.2	18.2	8
Total Non-Discounted Cumulative Cost														
(1) IBM ($Mil)	14.0	42.4	81.9	131	190	256	330	400	468	534	596	657	716	9
(2) DEC	18.4	53.6	102	163	233	311	397	477	553	625	693	785	820	10
(3) INT	22.9	67.3	128	202	288	383	486	582	672	756	835	909	979	11
Total Non-Discounted Cum. Cost Ratios														
(1) IBM	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	12
(2) DEC	1.28	1.26	1.24	1.24	1.23	1.21	1.20	1.19	1.18	1.17	1.16	1.15	1.14	13
(3) INT	1.64	1.59	1.56	1.54	1.56	1.50	1.47	1.46	1.44	1.42	1.40	1.38	1.37	14
Total Discounted Cumulative Cost														
(1) IBM ($Mil)	13.3	38.0	69.1	105	143	182	221	256	286	312	336	356	374	15
(2) DEC	17.2	48.1	86.5	130	175	222	267	307	340	370	395	416	435	16
(3) INT	21.9	60.3	108	161	217	274	329	376	416	450	470	503	525	17
Total Discounted Cum. Ratios														
(1) IBM	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	18
(2) DEC	1.29	1.26	1.25	1.24	1.22	1.22	1.21	1.20	1.19	1.18	1.18	1.17	1.16	19
(3) INT	1.65	1.59	1.56	1.53	1.52	1.50	1.49	1.47	1.45	1.44	1.42	1.41	1.40	20
Discount Factor (10%)	0.954	0.867	0.788	0.717	0.652	0.592	0.538	0.489	0.445	0.405	0.368	0.334	0.304	21

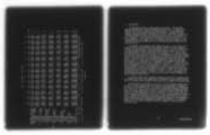
$\rho = 2$ $Q_j = 2 \times 10^6$ Dev. Cycle = 7 $\alpha = 0.65$ $g = 1.5$ $a = 0.8$ $b = 0.2$

$s_1, s_2, s_3 = 1.208, 1.000, 0.828$ $m_1, m_2, m_3 = 1.266, 0.928, 0.850$ $r_1, r_2, r_3 = 1.292, 0.938, 0.825$

Table 3-A.7

AD 487 ARMY ELECTRONICS COMMAND FORT MONMOUTH N J F/G 9/2
COMPUTER FAMILY ARCHITECTURE SELECTION COMMITTEE FINAL REPORT. --ETC(U)
SEP 77 A H COLEMAN, W SVIRSKY, A T IRWIN
UNCLASSIFIED ECOM-4535 NL

2 OF 2
ADA049487



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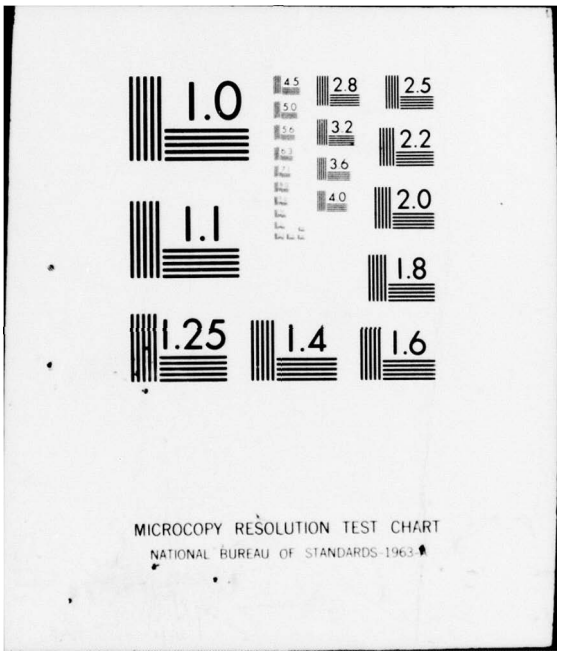
1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0
5.6
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Year Case 28

	1	2	3	4	5	6	7	8	9	10	11	12	13	
	78	79	80	81	82	83	84	85	86	87	88	89	90	Row
Base Appl. Sftwe Exp.	28.6	57.1	85.7	114	143	171	200	200	200	200	200	200	200	1
Base Hdwe Exp. ($Mil)	7.14	14.3	21.4	28.6	35.7	42.8	50.0	50.0	50.0	50.0	50.0	50.0	50.0	2
Total Yearly Software														
(1) IBM ($Mil)	19.4	37.7	51.3	62.6	71.8	79.3	85.4	79.2	73.6	68.5	63.8	59.6	55.8	3
(2) DEC	29.9	56.7	77.0	93.6	107	117	126	116	106	98.2	90.7	83.9	77.8	4
(3) INT	40.7	67.3	104	125	144	157	168	154	141	130	120	110	102	5
Total Yearly Hardware														
(1) IBM ($Mil)	4.26	8.59	12.9	17.2	21.4	25.7	30.0	30.0	30.0	30.0	30.0	30.0	30.0	6
(2) DEC	3.09	6.22	9.32	12.4	15.5	18.6	21.8	21.8	21.8	21.8	21.8	21.8	21.8	7
(3) INT	2.58	5.20	7.77	10.4	13.0	15.6	18.2	18.2	18.2	18.2	18.2	18.2	18.2	8
Total Non-Discounted Cumulative Cost														
(1) IBM ($Mil)	23.7	70.0	134	214	307	412	528	637	740	839	933	1022	1108	9
(2) DEC	33.0	95.9	182	288	411	546	694	831	960	1080	1192	1298	1397	10
(3) INT	43.3	125	236	372	529	702	888	1060	1219	1368	1505	1633	1753	11
Total Non-Discounted Cum. Cost Ratios														
(1) IBM	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	12
(2) DEC	1.39	1.37	1.36	1.34	1.34	1.32	1.31	1.30	1.30	1.29	1.28	1.27	1.26	13
(3) INT	1.83	1.78	1.76	1.74	1.72	1.70	1.68	1.66	1.65	1.63	1.61	1.60	1.58	14
Total Discounted Cumulative Cost														
(1) IBM ($Mil)	22.6	62.8	113	170	231	293	355	408	454	494	529	559	585	15
(2) DEC	31.5	86.0	154	230	310	390	469	536	593	642	684	719	749	16
(3) INT	41.3	112	200	298	400	502	601	685	756	816	867	910	946	17
Total Discounted Cum. Ratios														
(1) IBM	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	18
(2) DEC	1.39	1.37	1.36	1.35	1.34	1.33	1.32	1.31	1.31	1.30	1.29	1.29	1.28	19
(3) INT	1.83	1.78	1.77	1.75	1.73	1.71	1.69	1.68	1.66	1.65	1.64	1.63	1.62	20
Discount Factor (10%)	0.954	0.867	0.788	0.717	0.652	0.592	0.538	0.489	0.445	0.405	0.368	0.334	0.304	21

$\rho = 4$ $Q_j = 2 \times 10^6$ Dev. Cycle = 7 $\alpha = 0.65$ $g = 1.5$ $a = 0.8$ $b = 0.2$

$s_1, s_2, s_3 = 1.208, 1.000, 0.828$ $m_1, m_2, m_3 = 1.266, 0.928, 0.850$ $r_1, r_2, r_3 = 1.292, 0.938, 0.825$

Table 3-A.8

Case	Comment	Total Non-Discounted Cumulative Cost ($Mil), D_{8k} 1985 IBM	1985 DEC	1985 INT	Total Discounted Cumulative Cost ($Mil), D^*_{8k} 1985 IBM	1985 DEC	1985 INT	Total Non-Discounted Cumulative Cost ($Mil), D_{13k} 1990 IBM	1990 DEC	1990 INT	Total Discounted Cumulative Cost ($Mil), D^*_{13k} 1990 IBM	1990 DEC	1990 INT
18	Reference	282	300	344	179	192	221	520	531	592	268	278	314
31	Dev. Cycle = 5	339	362	416	221	238	274	577	593	665	310	324	368
32	Dev. Cycle = 10	207	219	250	131	140	160	440	445	494	217	224	251
33	α = 0.5	283	304	349	180	194	224	522	538	604	269	282	320
34	α = 0.8	282	296	338	179	190	217	519	523	581	267	275	308
35	g = 1	294	298	339	187	190	218	545	526	582	280	276	309
36	g = 2	276	301	346	176	193	222	509	533	598	262	280	317
37	a = 0.7	271	292	338	172	187	217	497	515	580	257	270	308
38	a = 0.9	294	308	350	187	197	225	543	546	604	280	286	320
39	b = 0.1	279	297	342	178	190	220	514	526	588	265	276	312
40	b = 0.3	285	302	346	181	194	222	526	536	597	271	281	316
41	u = 0.4	252	278	326	161	178	210	460	487	556	238	257	296
42	u = 0.6	312	322	362	198	206	232	580	574	629	298	300	332
43	v = 0.0	276	295	340	176	189	218	508	521	584	262	273	310
44	v = 0.4	288	305	348	183	195	223	532	541	601	274	283	318
45	U11/T1 = 0.6	305	300	344	194	192	221	556	531	592	288	278	314
46	U11/T1 = 0.8	263	300	344	167	192	221	489	531	592	251	278	314
47	U12/T2 = 0.4	282	327	344	179	210	221	520	573	592	268	302	314
48	U12/T2 = 0.6	282	263	344	179	168	221	520	471	592	268	246	314
49	U13/T3 = 0.2	282	300	408	179	192	263	520	531	694	268	278	370
50	U13/T3 = 0.4	282	300	309	179	192	198	520	531	538	268	278	284
51	s1 up 20%	302	291	337	192	186	216	560	513	579	288	269	307
52	s2 up 20%	272	313	338	173	200	218	500	557	582	258	292	309
53	s3 up 20%	275	295	354	175	189	227	505	520	613	261	273	324
54	m1 up 20%	292	295	339	185	189	218	539	521	584	277	273	310
55	m2 up 20%	278	307	341	177	196	219	512	544	587	264	285	312
56	m3 up 20%	278	297	349	177	190	224	513	525	604	264	276	320
57	r1 up 20%	292	295	339	185	189	218	539	520	584	278	273	310
58	r2 up 20%	278	307	341	177	196	219	512	544	587	264	285	312
59	r3 up 20%	279	297	349	177	190	224	513	525	604	264	276	320

Table 3-A.9

Case	Comment	Total Non-Discounted Cumulative Cost Ratios 1985, R_{8k} IBM	DEC	INT	Total Discounted Cumulative Cost Ratios 1985, R^*_{8k} IBM	DEC	INT	Total Non-Discounted Cumulative Cost Ratios 1990, $R_{13,k}$ IBM	DEC	INT	Total Discounted Cumulative Cost Ratios 1990, $R^*_{13,k}$ IBM	DEC	INT
18	Reference	1.00	1.06	1.22	1.00	1.07	1.23	1.00	1.02	1.14	1.00	1.04	1.17
31	Dev. Cycle = 5	1.00	1.07	1.23	1.00	1.08	1.24	1.00	1.03	1.15	1.00	1.04	1.19
32	Dev. Cycle = 10	1.00	1.06	1.21	1.00	1.07	1.22	1.00	1.01	1.12	1.00	1.03	1.16
33	α = 0.5	1.00	1.07	1.23	1.00	1.08	1.24	1.00	1.03	1.16	1.00	1.05	1.19
34	α = 0.8	1.00	1.05	1.20	1.00	1.06	1.21	1.00	1.01	1.12	1.00	**1.03**	**1.15**
35	g = 1	1.00	1.01	1.15	1.00	1.02	1.16	1.00	0.965	1.07	1.00	0.986	1.10
36	g = 2	1.00	1.09	1.25	1.00	1.10	1.26	1.00	1.05	1.17	1.00	1.07	1.21
37	a = 0.7	1.00	1.08	1.25	1.00	1.09	1.26	1.00	1.04	1.17	1.00	1.05	1.20
38	a = 0.9	1.00	1.05	1.19	1.00	1.05	1.20	1.00	1.00	1.11	1.00	1.02	1.14
39	b = 0.1	1.00	1.06	1.22	1.00	1.07	1.24	1.00	1.02	1.14	1.00	1.04	1.18
40	b = 0.3	1.00	1.06	1.21	1.00	1.07	1.23	1.00	1.02	1.13	1.00	1.04	1.17
41	u = 0.4	1.00	1.10	1.29	1.00	1.10	1.30	1.00	1.06	1.21	1.00	1.08	1.24
42	u = 0.6	1.00	**1.03**	1.16	1.00	1.04	1.17	1.00	0.990	1.08	1.00	1.01	1.11
43	v = 0.0	1.00	1.07	1.23	1.00	1.07	1.24	1.00	1.02	1.15	1.00	1.04	1.18
44	v = 0.4	1.00	1.06	1.21	1.00	1.06	1.22	1.00	1.02	1.13	1.00	1.03	1.16
45	U11/T1 = 0.6	1.00	0.984	1.13	1.00	0.990	1.14	1.00	0.955	1.06	1.00	0.965	1.09
46	U11/T1 = 0.8	1.00	1.14	1.31	1.00	1.15	1.32	1.00	1.08	1.21	1.00	1.11	1.25
47	U12/T2 = 0.4	1.00	1.16	1.22	1.00	1.17	1.23	1.00	1.10	1.14	1.00	1.13	1.17
48	U12/T2 = 0.6	1.00	0.933	1.22	1.00	0.938	1.23	1.00	0.906	1.14	1.00	0.918	1.17
49	U13/T3 = 0.2	1.00	1.06	1.45	1.00	1.07	1.47	1.00	1.02	1.33	1.00	1.04	1.38
50	U13/T3 = 0.4	1.00	1.06	1.10	1.00	1.07	1.11	1.00	1.02	1.03	1.00	1.04	1.06
51	s1 up 20%	1.00	0.964	1.12	1.00	0.969	1.12	1.00	0.916	1.03	1.00	0.934	1.06
52	s2 up 20%	1.00	1.15	1.24	1.00	1.16	1.26	1.00	1.11	1.16	1.00	1.13	1.20
53	s3 up 20%	1.00	1.07	1.29	1.00	1.08	1.30	1.00	1.03	1.21	1.00	1.04	1.24
54	m1 up 20%	1.00	1.01	1.16	1.00	1.02	1.18	1.00	0.967	1.08	1.00	0.986	1.12
55	m2 up 20%	1.00	1.10	1.23	1.00	1.11	1.24	1.00	1.06	1.15	1.00	1.08	1.18
56	m3 up 20%	1.00	1.07	1.26	1.00	1.07	1.26	1.00	1.02	1.18	1.00	1.04	1.21
57	r1 up 20%	1.00	1.01	1.16	1.00	1.02	1.18	1.00	0.965	1.08	1.00	0.982	1.12
58	r2 up 20%	1.00	1.10	1.23	1.00	1.11	1.24	1.00	1.06	1.15	1.00	1.08	1.18
59	r3 up 20%	1.00	1.06	1.25	1.00	1.07	1.26	1.00	1.02	1.18	1.00	1.04	1.21

Table 3-A.10

a. APPENDIX B - CORRECTIONS TO CALCULATIONS REFLECTING REVISED SUPPORT SOFTWARE DATA

At the 7 October 1976 meeting of the CFA Publications Subcommittee held at ECOM headquarters, Ft. Monmouth, New Jersey, Jim Wagner distributed a paper describing the revised results of the evaluation of the support software bases of the candidate architectures for the Military Computer Family [WagnJ76]. Its support software base results were different from those reported earlier in the main body of this report. The purpose of this appendix is to describe the main effects of these differences.

Figure 3-B.1 summarizes the revised software bases as reported in [WagnJ76]. Figure 3-B.2, also based on [WagnJ76], gives the estimated number of years to correct these deficiencies when 1, 2, and 3 million dollar/year are spent on support software development.

Software Base and Deficiency Comparison (M=10^6 dollars)

Existing Base		Deficiency	Total	Percent Availability
IBM	32.269M	9.595M	41.864M	77.08
DEC	22.220M	19.130M	41.350M	53.74
INT	15.360M	25.970M	41.330M	37.16

Figure 3-B.1

Years to Correct Deficiencies
Development Dollars

	1M	2M	3M
IBM	10.5	5.5	4.5
DEC	20.0	11	8.5
INT	26.0	15	10

Figure 3-B.2

Using the values given in Figure3-B.1, and in some cases applying the expressions described earlier, we obtained new input values for some of the parameters in the model:

Parameter	Old Value	New Value
U_{11}	31.049M	32.269M
U_{12}	20.079M	22.220M
U_{13}	14.100M	15.360M
T_1	44.604M	41.864M
T_2	43.893M	41.350M
T_3	44.040M	41.330M
s'	49.7	55.99
k'	0.05601	0.06337
f_m	0.0795	0.08996
f_M	2.7528	3.11464

In the earlier calculations, Q_j, the support software expenditure, was assumed to be a constant two million for the years J=2 through 13 (for most of the cases). The following calculations improve upon this assumption by making better use of the data provided in [WagnJ76]. In particular, we see from Figure 3-B.2 that if we spend two million per year it actually takes eleven years, or twenty-two million dollars, to correct a 19.30 million dollar deficiency in support software. This implies that in this case the dollar-effectiveness factor is (19.13/22) or 0.870 for the PDP-11. The comparable figures for the Interdata 8/32 and IBM 360/370 are 0.866 and 0.872, respectively. To account for these effects in the revised calculations we replaced U_{jk} in Eq. (3.24) by $\gamma_k U_{jk}$ where $\gamma(1) = 0.872$, $\gamma(2) = 0.870$, and $\gamma(3) = 0.866$. Also we replaced Q_j by Q_{jk} in Eqs. (3.18) and (3.28) and for the \$2 million dollar expenditure rate, let the Q_{jk} matrix be zero except for the following elements:

$$Q_{j1} = 2\text{x}10^6 \text{ , } j=2, \ldots 7$$

$$Q_{j2} = 2\text{x}10^6 \text{ , } j=2, \ldots 12$$

$$Q_{j3} = 2\text{x}10^6 \text{ , } j=2, \ldots 16$$

The earlier calculations had assumed Q_{jk} would be constant for all years, except the first, and thus didn't take into account the fact that once the support software deficiency had been corrected further expenditures would not be necessary.

Figures 3-B.1 and 3-B.2, and Tables 3-B.1 through 3-B.6 summarize the revised results for cases 3, 8, 13, 18, 23, and 28. Table 3-B.7 gives the results of assuming a software-to-hardware ratio of eight.

Comparing the revised results shown in Tables 3-B.1 through 3-B.7 with Figures 3-1 and 3-2, of the main text of this paper, we see the corrections have a relatively insignificant effect on the cost ratios reported earlier.

WagnJ76 Wagner, J., et. al., "Procedure for and Results of the Evaluation of the Software Bases of the Candidate Architectures for the Military Computer Family," 6 August 1976. Prepared by the Software Evaluation Methodology Subcommittee.

Year Case 3 (19 Oct 76)

	1	2	3	4	5	6	7	8	9	10	11	12	13	
	78	79	80	81	82	83	84	85	86	87	88	89	90	Row
Base Appl. Sftwe Exp.	0.893	1.78	2.68	3.57	4.46	5.36	6.25	6.25	6.25	6.25	6.25	6.25	6.25	1
Base Hdwe Exp. ($Mil)	7.14	14.3	21.4	28.6	35.7	42.8	50.0	50.0	50.0	50.0	50.0	50.0	50.0	2
Total Yearly Software														
(1) IBM ($Mil)	0.719	3.32	3.84	4.27	4.63	4.94	5.18	3.18	3.18	3.18	3.18	3.18	3.18	3
(2) DEC	1.07	3.96	4.72	5.34	5.85	6.27	6.60	6.25	5.93	5.64	5.37	5.13	3.13	4
(3) INT	1.43	4.63	5.64	6.45	7.12	7.67	8.09	7.62	7.18	6.78	6.42	6.09	5.79	5
Total Yearly Hardware														
(1) IBM ($Mil)	4.26	8.59	12.9	17.2	21.4	25.7	30.0	30.0	30.0	30.0	30.0	30.0	30.0	6
(2) DEC	3.09	6.22	9.32	12.4	15.5	18.6	21.8	21.8	21.8	21.8	21.8	21.8	21.8	7
(3) INT	2.58	5.20	7.77	10.4	13.0	15.6	18.2	18.2	18.2	18.2	18.2	18.2	18.2	8
Total Non-Discounted Cumulative Cost														
(1) IBM ($Mil)	4.98	1.69	33.6	55.0	81.1	112	147	180	213	246	280	313	346	9
(2) DEC	4.16	14.4	28.4	46.2	67.6	92.5	121	149	177	204	231	258	2837	10
(3) INT	4.01	13.8	27.2	44.1	64.2	87.4	114	139	165	190	214	239	262	11
Total Non-Discounted Cum. Cost Ratios														
(1) IBM	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	12
(2) DEC	0.835	0.852	0.845	0.840	0.834	0.826	0.823	0.838	0.831	0.829	0.825	0.824	0.818	13
(3) INT	0.805	0.816	0.810	0.802	0.792	0.780	0.776	0.772	0.775	0.772	0.764	0.764	0.757	14
Total Discounted Cumulative Cost														
(1) IBM ($Mil)	4.75	15.1	28.2	43.6	60.6	78.7	97.5	114	128	142	154	165	175	15
(2) DEC	3.97	12.8	23.9	36.6	50.6	65.3	80.4	94.1	106	118	128	136	144	16
(3) INT	3.83	12.4	22.9	35.0	48.1	61.8	75.8	88.4	99.7	110	119	127	134	17
Total Discounted Cum. Ratios														
(1) IBM	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	18
(2) DEC	0.836	0.848	0.848	0.839	0.835	0.830	0.825	0.825	0.828	0.831	0.831	0.824	0.823	19
(3) INT	0.806	0.821	0.812	0.803	0.794	0.785	0.777	0.775	0.779	0.775	0.773	0.770	0.766	20
Discount Factor (10%)	0.954	0.867	0.788	0.717	0.652	0.592	0.538	0.489	0.445	0.405	0.368	0.334	0.304	21

ρ = 1/8 Dev. Cycle = 7 α = 0.65 g = 1.5 a = 0.8 b = 0.2 Revised Support Software Base

s_1, s_2, s_3 = 1.208, 1.000, 0.828 m_1, m_2, m_3 = 1.266, 0.928, 0.850 r_1, r_2, r_3 = 1.292, 0.938 0.825

Table 3-B.1

Year Case 8 (19 Oct 76)

	1	2	3	4	5	6	7	8	9	10	11	12	13	
	78	79	80	81	82	83	84	85	86	87	88	89	90	Row
Base Appl. Sftwe Exp.	1.78	3.57	5.36	7.14	8.93	10.7	12.5	12.5	12.5	12.5	12.5	12.5	12.5	1
Base Hdwe Exp. ($Mil)	7.14	14.3	21.4	28.6	35.7	42.8	50.0	50.0	50.0	50.0	50.0	50.0	50.0	2
Total Yearly Software														
(1) IBM ($Mil)	1.43	4.66	5.69	6.55	7.27	7.86	8.36	6.36	6.36	6.36	6.36	6.36	6.36	3
(2) DEC	2.14	5.94	7.45	8.69	9.71	10.5	11.2	10.5	9.86	9.28	8.75	8.26	6.26	4
(3) INT	2.86	7.27	9.27	10.9	12.3	13.3	14.2	13.2	12.3	11.6	10.8	10.2	9.57	5
Total Yearly Hardware														
(1) IBM ($Mil)	4.26	8.59	12.9	17.2	21.4	25.7	30.0	30.0	30.0	30.0	30.0	30.0	30.0	6
(2) DEC	3.09	6.22	9.32	12.4	15.5	18.6	21.8	21.8	21.8	21.8	21.8	21.8	21.8	7
(3) INT	2.58	5.20	7.77	10.4	13.0	15.6	18.2	18.2	18.2	18.2	18.2	18.2	18.2	8
Total Non-Discounted Cumulative Cost														
(1) IBM ($Mil)	5.69	18.9	37.5	61.2	89.9	124	162	198	235	271	307	344	380	9
(2) DEC	5.23	17.4	34.2	55.3	80.6	110	143	175	207	283	268	298	326	10
(3) INT	5.44	17.9	35.0	56.2	81.5	110	143	174	205	234	263	292	319	11
Total Non-Discounted Cum. Cost Ratios														
(1) IBM	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	12
(2) DEC	0.919	0.921	0.912	0.904	0.896	0.887	0.883	0.884	0.881	0.878	0.873	0.866	0.858	13
(3) INT	0.956	0.947	0.933	0.918	0.906	0.887	0.883	0.879	0.872	0.863	0.857	0.849	0.839	14
Total Discounted Cumulative Cost														
(1) IBM ($Mil)	5.43	16.9	31.5	48.5	67.2	87.1	108	125	142	156	170	182	193	15
(2) DEC	4.99	15.5	28.7	43.9	60.4	77.6	95.2	111	125	138	149	159	167	16
(3) INT	5.19	16.0	29.4	44.7	61.2	78.2	95.5	111	124	136	147	157	165	17
Total Discounted Cum. Ratios														
(1) IBM	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	18
(2) DEC	0.919	0.917	0.911	0.905	0.899	0.891	0.881	0.888	0.880	0.885	0.876	0.874	0.865	19
(3) INT	0.956	0.947	0.933	0.922	0.911	0.898	0.884	0.868	0.873	0.872	0.865	0.863	0.855	20
Discount Factor (10%)	0.954	0.867	0.788	0.717	0.652	0.592	0.538	0.489	0.445	0.405	0.368	0.334	0.304	21

ρ = 1/4 Dev. Cycle = 7 α = 0.65 g = 1.5 a = 0.8 b = 0.2 Revised Support Software Base

s_1, s_2, s_3 = 1.208, 1.000, 0.828 m_1, m_2, m_3 = 1.266, 0.928, 0.850 r_1, r_2, r_3 = 1.292, 0.938 0.825

Table 3-B.2

Year Case 13 (19 Oct 76)

	1	2	3	4	5	6	7	8	9	10	11	12	13	
	78	79	80	81	82	83	84	85	86	87	88	89	90	Row
Base Appl. Sftwe Exp.	3.57	7.14	10.7	14.3	17.9	21.4	25.0	25.0	25.0	25.0	25.0	25.0	25.0	1
Base Hdwe Exp. ($Mil)	7.14	14.3	21.4	28.6	35.7	42.8	50.0	50.0	50.0	50.0	50.0	50.0	50.0	2
Total Yearly Software														
(1) IBM ($Mil)	2.88	7.31	9.36	11.1	12.6	13.7	14.7	12.7	12.7	12.7	12.7	12.7	12.7	3
(2) DEC	4.28	9.88	12.9	15.4	17.5	19.0	20.4	19.0	17.7	16.6	15.5	14.5	12.5	4
(3) INT	5.74	12.5	16.5	19.8	22.6	24.6	26.4	24.5	22.7	21.1	19.7	18.4	17.1	5
Total Yearly Hardware														
(1) IBM ($Mil)	4.26	8.59	12.9	17.2	21.4	25.7	30.0	30.0	30.0	30.0	30.0	30.0	30.0	6
(2) DEC	3.09	6.22	9.32	12.4	15.5	18.6	21.8	21.8	21.8	21.8	21.8	21.8	21.8	7
(3) INT	2.58	5.20	7.77	10.4	13.0	15.6	18.2	18.2	18.2	18.2	18.2	18.2	18.2	8
Total Non-Discounted Cumulative Cost														
(1) IBM ($Mil)	7.14	23.0	45.2	73.5	108	147	192	234	277	320	363	405	448	9
(2) DEC	7.37	23.5	45.7	73.5	106	144	186	227	267	305	342	378	413	10
(3) INT	8.32	26.0	50.4	80.6	116	156	201	244	284	324	362	398	433	11
Total Non-Discounted Cum. Cost Ratios														
(1) IBM	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	12
(2) DEC	1.03	1.02	1.01	1.00	0.981	0.980	0.969	0.970	0.964	0.953	0.942	0.933	0.922	13
(3) INT	1.16	1.13	1.12	1.10	1.07	1.06	1.05	1.04	1.02	1.01	0.997	0.983	0.966	14
Total Discounted Cumulative Cost														
(1) IBM ($Mil)	6.81	2.06	38.1	58.4	80.6	104	128	149	168	185	201	215	228	15
(2) DEC	7.04	21.0	38.5	58.4	80.0	102	125	145	162	178	192	204	214	16
(3) INT	7.93	23.3	42.4	64.1	87.3	111	135	156	174	190	204	216	227	17
Total Discounted Cum. Ratios														
(1) IBM	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	18
(2) DEC	1.03	1.02	1.01	1.00	0.992	0.981	0.976	0.973	0.964	0.962	0.955	0.949	0.938	19
(3) INT	1.16	1.13	1.11	1.10	1.08	1.07	1.05	1.05	1.04	1.03	1.01	1.00	0.996	20
Discount Factor (10%)	0.954	0.867	0.788	0.717	0.652	0.592	0.538	0.489	0.445	0.405	0.368	0.334	0.304	21

ρ = 1/2 Dev. Cycle = 7 α = 0.65 g = 1.5 a = 0.8 b = 0.2 Revised Support Software Base

s_1, s_2, s_3 = 1.208, 1.000, 0.828 m_1, m_2, m_3 = 1.266, 0.928, 0.850 r_1, r_2, r_3 = 1.292, 0.938 0.825

Table 3-B.3

Year Case 18 (Reference, 19 Oct 76)

	1	2	3	4	5	6	7	8	9	10	11	12	13	
	78	79	80	81	82	83	84	85	86	87	88	89	90	Row
Base Appl. Sftwe Exp.	7.14	14.3	21.4	28.6	35.7	42.8	50.0	50.0	50.0	50.0	50.0	50.0	50.0	1
Base Hdwe Exp. ($Mil)	7.14	14.3	21.4	28.6	35.7	42.8	50.0	50.0	50.0	50.0	50.0	50.0	50.0	2
Total Yearly Software														
(1) IBM ($Mil)	5.75	12.6	16.7	20.2	23.1	25.5	25.4	25.4	25.4	25.4	25.4	25.4	25.4	3
(2) DEC	8.57	17.8	23.8	28.8	32.8	36.1	38.8	36.0	33.4	31.1	29.0	27.0	25.0	4
(3) INT	11.5	23.1	31.1	37.7	43.0	47.3	50.7	46.9	43.4	40.3	37.4	34.7	32.3	5
Total Yearly Hardware														
(1) IBM ($Mil)	4.26	8.59	12.9	17.2	21.4	25.7	30.0	30.0	30.0	30.0	30.0	30.0	30.0	6
(2) DEC	3.09	6.22	9.32	12.4	15.5	18.6	21.8	21.8	21.8	21.8	21.8	21.8	21.8	7
(3) INT	2.58	5.20	7.77	10.4	13.0	15.6	18.2	18.2	18.2	18.2	18.2	18.2	18.2	8
Total Non-Discounted Cumulative Cost														
(1) IBM ($Mil)	10.0	31.2	60.8	98.2	143	194	251	307	362	418	473	528	584	9
(2) DEC	11.6	35.7	68.8	110	158	213	274	331	387	440	490	539	586	10
(3) INT	14.0	42.3	81.2	129	185	248	317	382	444	502	558	610	661	11
Total Non-Discounted Cum. Cost Ratios														
(1) IBM	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	12
(2) DEC	1.16	1.14	1.13	1.12	1.10	1.10	1.09	1.08	1.07	1.05	1.04	1.02	1.00	13
(3) INT	1.40	1.36	1.34	1.31	1.29	1.28	1.26	1.24	1.23	1.20	1.18	1.16	1.13	14
Total Discounted Cumulative Cost														
(1) IBM ($Mil)	9.55	28.0	51.3	78.1	107	137	168	195	220	242	263	281	298	15
(2) DEC	11.1	31.9	58.0	87.6	119	152	184	212	237	258	277	293	307	16
(3) INT	13.4	37.9	68.6	103	140	177	213	245	273	296	317	334	350	17
Total Discounted Cum. Ratios														
(1) IBM	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	18
(2) DEC	1.16	1.14	1.13	1.12	1.11	1.11	1.09	1.09	1.08	1.07	1.05	1.04	1.03	19
(3) INT	1.40	1.35	1.34	1.32	1.31	1.29	1.27	1.26	1.24	1.22	1.20	1.19	1.17	20
Discount Factor (10%)	0.954	0.867	0.788	0.717	0.652	0.592	0.538	0.489	0.445	0.405	0.368	0.334	0.304	21

$\rho = 1$ Dev. Cycle = 7 $\alpha = 0.65$ $g = 1.5$ $a = 0.8$ $b = 0.2$ Revised Support Software Base

$s_1, s_2, s_3 = 1.208, 1.000, 0.828$ $m_1, m_2, m_3 = 1.266, 0.928, 0.850$ $r_1, r_2, r_3 = 1.292, 0.938\ 0.825$

Table 3-B.4

Year Case 23 (19 Oct 76)

	1	2	3	4	5	6	7	8	9	10	11	12	13	
	78	79	80	81	82	83	84	85	86	87	88	89	90	Row
Base Appl. Sftwe Exp.	14.3	28.6	42.9	57.1	71.4	85.7	100	100	100	100	100	100	100	1
Base Hdwe Exp. ($Mil)	7.14	14.3	21.4	28.6	35.7	42.8	50.0	50.0	50.0	50.0	50.0	50.0	50.0	2
Total Yearly Software														
(1) IBM ($Mil)	11.5	23.3	31.5	38.4	44.2	48.9	52.8	50.8	50.8	50.8	50.8	50.8	50.8	3
(2) DEC	17.2	33.6	45.6	55.5	63.6	70.3	75.6	70.0	64.9	60.3	56.0	52.1	50.1	4
(3) INT	23.0	44.2	60.2	73.3	84.0	92.6	99.4	91.8	84.9	78.5	72.7	67.4	62.6	5
Total Yearly Hardware														
(1) IBM ($Mil)	4.26	8.59	12.9	17.2	21.4	25.7	30.0	30.0	30.0	30.0	30.0	30.0	30.0	6
(2) DEC	3.09	6.22	9.32	12.4	15.5	18.6	21.8	21.8	21.8	21.8	21.8	21.8	21.8	7
(3) INT	2.58	5.20	7.77	10.4	13.0	15.6	18.2	18.2	18.2	18.2	18.2	18.2	18.2	8
Total Non-Discounted Cumulative Cost														
(1) IBM ($Mil)	15.8	47.6	92.0	148	213	288	371	452	532	613	694	775	856	9
(2) DEC	20.2	60.0	115	183	262	351	448	540	627	709	787	860	932	10
(3) INT	25.6	75.0	143	227	324	432	549	659	762	859	950	1036	1116	11
Total Non-Discounted Cum. Cost Ratios														
(1) IBM	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	12
(2) DEC	1.28	1.26	1.25	1.24	1.23	1.22	1.21	1.19	1.18	1.16	1.13	1.11	1.09	13
(3) INT	1.62	1.58	1.55	1.53	1.52	1.50	1.48	1.46	1.43	1.40	1.37	1.34	1.30	14
Total Discounted Cumulative Cost														
(1) IBM ($Mil)	15.0	42.7	77.6	118	160	204	249	288	324	357	387	414	438	15
(2) DEC	19.3	53.8	97.1	146	197	250	302	347	385	419	447	472	494	16
(3) INT	24.4	67.2	121	181	244	308	371	425	470	510	543	572	596	17
Total Discounted Cum. Ratios														
(1) IBM	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	18
(2) DEC	1.29	1.26	1.25	1.24	1.23	1.22	1.21	1.20	1.19	1.17	1.16	1.40	1.13	19
(3) INT	1.63	1.57	1.56	1.53	1.52	1.51	1.49	1.48	1.45	1.43	1.40	1.38	1.36	20
Discount Factor (10%)	0.954	0.867	0.788	0.717	0.652	0.592	0.538	0.489	0.445	0.405	0.368	0.334	0.304	21

$\rho = 2$ Dev. Cycle = 7 $\alpha = 0.65$ $g = 1.5$ $a = 0.8$ $b = 0.2$ Revised Support Software Base

$s_1, s_2, s_3 = 1.208, 1.000, 0.828$ $m_1, m_2, m_3 = 1.266, 0.928, 0.850$ $r_1, r_2, r_3 = 1.292, 0.938, 0.825$

Table 3-B.5

Year Case 28 (19 Oct 76)

	1	2	3	4	5	6	7	8	9	10	11	12	13	
	78	79	80	81	82	83	84	85	86	87	88	89	90	Row
Base Appl. Sftwe Exp.	28.6	57.1	85.7	114	143	171	200	200	200	200	200	200	200	1
Base Hdwe Exp. ($Mil)	7.14	14.3	21.4	28.6	35.7	42.8	50.0	50.0	50.0	50.0	50.0	50.0	50.0	2
Total Yearly Software														
(1) IBM ($Mil)	23.0	44.5	61.0	74.6	86.4	95.6	104	102	102	102	102	102	102	3
(2) DEC	34.3	65.0	89.1	109	126	138	149	138	128	118	110	102	100	4
(3) INT	46.0	86.3	118	144	166	183	197	182	168	155	144	133	123	5
Total Yearly Hardware														
(1) IBM ($Mil)	4.26	8.59	12.9	17.2	21.4	25.7	30.0	30.0	30.0	30.0	30.0	30.0	30.0	6
(2) DEC	3.09	6.22	9.32	12.4	15.5	18.6	21.8	21.8	21.8	21.8	21.8	21.8	21.8	7
(3) INT	2.58	5.20	7.77	10.4	13.0	15.6	18.2	18.2	18.2	18.2	18.2	18.2	18.2	8
Total Non-Discounted Cumulative Cost														
(1) IBM ($Mil)	27.3	80.4	154	246	354	475	609	741	872	1004	1136	1267	1399	9
(2) DEC	37.4	109	207	328	469	626	797	957	1106	1247	1379	1503	1625	10
(3) INT	48.5	140	266	421	600	798	1013	1213	1399	1573	1734	1885	2026	11
Total Non-Discounted Cum. Cost Ratios														
(1) IBM	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	12
(2) DEC	1.37	1.36	1.34	1.33	1.32	1.32	1.31	1.29	1.27	1.24	1.21	1.19	1.16	13
(3) INT	1.78	1.74	1.73	1.71	1.69	1.68	1.66	1.64	1.60	1.57	1.53	1.49	1.45	14
Total Discounted Cumulative Cost														
(1) IBM ($Mil)	26.0	72.1	130	196	266	338	410	474	532	586	634	678	718	15
(2) DEC	35.7	97.5	175	262	354	447	538	616	683	739	788	829	866	16
(3) INT	46.3	126	225	336	453	570	685	783	865	936	995	1045	1088	17
Total Discounted Cum. Ratios														
(1) IBM	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	18
(2) DEC	1.37	1.35	1.35	1.34	1.33	1.32	1.31	1.30	1.28	1.26	1.24	1.22	1.21	19
(3) INT	1.78	1.75	1.73	1.71	1.70	1.69	1.67	1.65	1.62	1.60	1.57	1.54	1.52	20
Discount Factor (10%)	0.954	0.867	0.788	0.717	0.652	0.592	0.538	0.489	0.445	0.405	0.368	0.334	0.304	21

$\rho = 4$ Dev. Cycle = 7 $\alpha = 0.65$ $g = 1.5$ $a = 0.8$ $b = 0.2$ Revised Support Software Base

$s_1, s_2, s_3 = 1.208, 1.000, 0.828$ $m_1, m_2, m_3 = 1.266, 0.928, 0.850$ $r_1, r_2, r_3 = 1.292, 0.938\ 0.825$

Table 3-B.6

Year Extra Case (19 Oct 76)

	1	2	3	4	5	6	7	8	9	10	11	12	13	
	78	79	80	81	82	83	84	85	86	87	88	89	90	Row
Base Appl. Sftwe Exp.	57.1	114	171	228	286	343	400	400	400	400	400	400	400	1
Base Hdwe Exp. ($Mil)	7.14	14.3	21.4	28.6	35.7	42.8	50.0	50.0	50.0	50.0	50.0	50.0	50.0	2
Total Yearly Software														
(1) IBM ($Mil)	46.0	86.8	120	147	171	190	205	203	203	203	203	203	203	3
(2) DEC	68.5	128	176	216	249	275	296	274	254	235	218	202	201	4
(3) INT	91.7	170	234	287	330	365	392	361	334	308	285	264	244	5
Total Yearly Hardware														
(1) IBM ($Mil)	4.26	8.59	12.9	17.2	21.4	25.7	30.0	30.0	30.0	30.0	30.0	30.0	30.0	6
(2) DEC	3.09	6.22	9.32	12.4	15.5	18.6	21.8	21.8	21.8	21.8	21.8	21.8	21.8	7
(3) INT	2.58	5.20	7.77	10.4	13.0	15.6	18.2	18.2	18.2	18.2	18.2	18.2	18.2	8
Total Non-Discounted Cumulative Cost														
(1) IBM ($Mil)	50.2	146	278	443	635	850	1086	1319	1553	1786	2019	2253	2486	9
(2) DEC	71.6	206	391	619	883	1177	1495	1791	2066	2323	2563	2787	3010	10
(3) INT	94.3	270	512	809	1152	1532	1942	2322	2674	3000	3303	3585	3847	11
Total Non-Discounted Cum. Cost Ratios														
(1) IBM	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	12
(2) DEC	1.43	1.41	1.41	1.40	1.30	1.38	1.38	1.36	1.33	1.30	1.27	1.24	1.21	13
(3) INT	1.88	1.85	1.84	1.83	1.81	1.80	1.79	1.76	1.72	1.68	1.64	1.59	1.55	14
Total Discounted Cumulative Cost														
(1) IBM ($Mil)	47.9	131	235	353	478	606	731	846	949	1044	1130	1208	1279	15
(2) DEC	68.3	185	330	494	666	840	1010	1155	1277	1381	1469	1544	1612	16
(3) INT	90.0	242	433	646	870	1095	1313	1499	1655	1788	1899	1993	2073	17
Total Discounted Cum. Ratios														
(1) IBM	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	18
(2) DEC	1.42	1.41	1.40	1.40	1.39	1.39	1.38	1.36	1.34	1.32	1.30	1.28	1.26	19
(3) INT	1.88	1.85	1.84	1.83	1.82	1.81	1.80	1.77	1.74	1.71	1.68	1.65	1.62	20
Discount Factor (10%)	0.954	0.867	0.788	0.717	0.652	0.592	0.538	0.489	0.445	0.405	0.368	0.334	0.304	21

$\rho = 8$ Dev. Cycle = 7 $\alpha = 0.65$ $g = 1.5$ $a = 0.8$ $b = 0.2$ Revised Support Software Base

$s_1, s_2, s_3 = 1.208, 1.000, 0.828$ $m_1, m_2, m_3 = 1.266, 0.928, 0.850$ $r_1, r_2, r_3 = 1.292, 0.938, 0.825$

Table 3-B.7

4. CONCLUSIONS

The two models serve as checks against one another. The bottom-up results indicate that in most circumstances the DEC PDP-11 is superior to both the IBM S/370 and Interdata 8/32 architectures. The top-down model results, on the other hand, indicate that the S/370 is superior for high (greater than one) software-to-hardware cost ratios, while the Interdata 8/32 is slightly better for low (less than one-fourth) ratios, and the PDP-11 is best in between. These apparently conflicting results were found to be due to uncertainties in the input data, to different input requirements, to contrasting basic model assumptions, and to different methods of combining the same input data.

For example, the bottom-up model weights the raw S, M, and R data, provided by CMU for the individual test programs, according to the estimated relevance of each program in each system application. It then combines these into the composite processor speed and static storage ratios, a_{ij}, and b_{ij}. The top-down model, on the other hand, uses composite S, M, R ratios, which were derived by CMU from the individual S, M, R measures for each test program and which were weighted by CMU to obtain minimum statistical variance in these ratios rather than to reflect the importance of particular application programs. A result of these two different approaches to using the individual test program S, M, and R data is a difference in the computed architectural efficiency of the Interdata 8/32 as compared to the PDP-11. In the first case they are comparable, in the second the 8/32 is superior. A further result of this difference is that if the unweighted S, M, and R data are used in the bottom-up model, then the 8/32 becomes the superior architecture in the 1976 calculations when the hardware-software cost ratio is high. This agrees with the top-down model results. Conversely, if the S, M, and R data used in the top-down model were weighted as in the bottom-up model, better agreement between the models would result.

As another example, the assumptions leading to the ratio of software costs to hardware costs are clearly among the most important to the ultimate results, while at the same time are among the most difficult to support with actual data.

The uncertainty calculations in Section 3.4 for the top-down model could be applied to the bottom-up model with similar results expected. Because of the size of these uncertainties, the results of the models must be interpreted with caution. By chance, each of the three architectures evaluated had either superior hardware attributes (the 8/32), or superior software attributes (the S/370), or a good combination of the two (the PDP-11). As a result, the combined hardware-software effectiveness of the three architectures were relatively close. Probably the strongest conclusions to be derived from the life cycle cost evaluations are that, within the uncertainties resulting from propagating errors in the input data throughout each models calculations, (1) the models agree and (2) all three architectures would be comparable choices based on life-cycle costs.