AECL-6533

ATOMIC ENERGY
OF CANADA LIMITED

L'ÉNERGIE ATOMIQUE
DU CANADA LIMITÉE

A PRACTICAL TECHNIQUE FOR BENEFIT-COST ANALYSIS OF COMPUTER-AIDED DESIGN AND DRAFTING SYSTEMS

**Technique commode pour analyser les bénéfices et les couts
des systèmes de conception et de dessin aidés par ordinateur**

R.R. SHAH and G. YAN

CERN LIBRARIES, GENEVA

CM-P00067601

Chalk River Nuclear Laboratories

Laboratoires nucléaires de Chalk River

Chalk River, Ontario

March 1979 mars

A PRACTICAL TECHNIQUE FOR BENEFIT-COST ANALYSIS OF
COMPUTER-AIDED DESIGN AND DRAFTING SYSTEMS

by

R.R. Shah and G. Yan

Reprinted from

No.15 Design Automation Conference Proceedings
June 19-21, 1978, Las Vegas, Nevada (78CH1363-1C)

Chalk River Nuclear Laboratories
Chalk River, Ontario
March 1979

AECL-6533

Technique commode pour analyser les bénéfices
et les coûts des systèmes de conception et de
dessin aidés par ordinateur*

par

R.R. Shah et G. Yan

Résumé

Il est nécessaire d'analyser les bénéfices et les coûts de l'exploitation des systèmes de conception et de dessin aidés par ordinateur afin de pouvoir justifier économiquement l'acquisition de nouveaux systèmes et évaluer la performance des installations existantes. Il est, cependant, difficile dans la pratique de faire de telles analyses car la plupart des avantages économique et techniques de ces systèmes sont "irréductibles" c'est-à-dire qu'il n'est pas facile de les traduire en termes monétaires.

On présente, dans ce rapport, une technique commode pour faire l'analyse économique des systèmes de conception et de dessin aidés par ordinateur dans l'environnement d'un bureau de dessin. On a recours à une approche basée sur le "pire cas" étant donné que l'augmentation de la productivité de la main-d'oeuvre actuelle est le seul bénéfice considéré, alors que tous les frais prévus sont pris en compte. On décrit les méthodes permettant d'estimer les bénéfices et les coûts. On illustre le mode d'analyse employé au moyen d'un cas typique d'étude des activités des bureaux de dessin de l'EACL.

*Tiré à part des comptes rendus N°15 du Congrès sur l'automatisation des dessins, tenu du 21 au 23 juin 1978 à Las Vegas, NV (78CH1363-1C)

L'Energie Atomique du Canada, Limitée
Laboratoires nucléaires de Chalk River
Chalk River, Ontario

Mars 1979

AECL-6533

ATOMIC ENERGY OF CANADA LIMITED

A PRACTICAL TECHNIQUE FOR BENEFIT-COST ANALYSIS OF
COMPUTER-AIDED DESIGN AND DRAFTING SYSTEMS

by

R.R. Shah and G. Yan

ABSTRACT

Analyses of benefits and costs associated with the operation of Computer-Aided Design and Drafting Systems (CADDs) are needed to derive economic justification for acquiring new systems, as well as to evaluate the performance of existing installations. In practice, however, such analyses are difficult to perform since most technical and economic advantages of CADDs are "irreducibles", i.e. cannot be readily translated into monetary terms.

In this paper, a practical technique for economic analysis of CADDs in a drawing office environment is presented. A "worst case" approach is taken since increase in productivity of existing manpower is the only benefit considered, while all foreseen costs are taken into account. Methods of estimating benefits and costs are described. The procedure for performing the analysis is illustrated by a case study based on the drawing office activities at Atomic Energy of Canada Limited.

Reprinted from No. 15 Design Automation Conference Proceedings, June 21-23, 1978, Las Vegas, NV, (78CH1363-1C).

Chalk River Nuclear Laboratories
Chalk River, Ontario

1979 March

AECL-6533

A PRACTICAL TECHNIQUE FOR BENEFIT-COST ANALYSIS OF
COMPUTER-AIDED DESIGN AND DRAFTING SYSTEMS

R.R. Shah and G. Yan
Atomic Energy of Canada Limited
Chalk River Nuclear Laboratories
Chalk River, Ontario

ABSTRACT

Analyses of benefits and costs associated with the operation of Computer-Aided Design and Drafting Systems (CADDs) are needed to derive economic justification for acquiring new systems, as well as to evaluate the performance of existing installations. In practice, however, such analyses are difficult to perform since most technical and economic advantages of CADDs are "irreducibles", i.e. cannot be readily translated into monetary terms.

In this paper, a practical technique for economic analysis of CADDs in a drawing office environment is presented. A "worst case" approach is taken since increase in productivity of existing manpower is the only benefit considered, while all foreseen costs are taken into account. Methods of estimating benefits and costs are described. The procedure for performing the analysis is illustrated by a case study based on the drawing office activities at Atomic Energy of Canada Limited.

INTRODUCTION

Analyses of both benefits and costs associated with the operation of Computer-Aided Design and Drafting Systems (CADDs)* are necessary when considering acquiring new systems, as well as when evaluating the performance of existing installations. Cost analysis is usually straightforward since all direct costs, e.g. capital and operating costs, can be easily identified and quantified. On the other hand, technical and economic benefits of CADDs are dependent upon data that are not readily available, making benefit analysis more difficult.

The need for a practical benefit-cost analysis arose during an engineering study carried out at Atomic Energy of Canada Limited (AECL) to investigate the application of computer-aided design and drafting techniques in the company's drawing office.

A literature survey revealed few published studies relating economic principles to CADDs. Qualitative description of methodologies for benefit-cost analyses were discussed by Dunn¹, Cotton², Meyers³, and Laxon⁴.

The paper by Potoczniak, et al.⁵ analysed costs and relative advantages of different computer graphic configurations but did not describe the economic benefits of these systems.

A more analytical approach to the subject was taken by Chasen⁶. His paper presented the economic principles for interactive graphics applications well. However, the study is difficult to apply to a drawing office environment since methods for estimating benefit and cost parameters were not explicitly stated.

Presented in this paper is a technique for CADDs benefit-cost analysis which was developed specifically

for the AECL drawing office activities. Data from the AECL engineering study are used to illustrate the application of this technique.

BENEFIT-COST ANALYSIS

The simple principle used in the benefit-cost analysis is:

$$\text{Benefits (B)} - \text{Costs (C)} = \text{Net Gain (G)}$$

Net gain G is a measure of the economic viability of the installation.

Benefits in producing drawings arise out of the numerous advantages offered by CADDs which include:

- increase in productivity of existing manpower,
- reduction in turn-around time for original drawings and for revisions,
- improvement in design flexibility,
- uniformity in drafting practices, and
- consistent high quality ink drawings for good reproductions and microfilming.

Cost of implementing CADDs comprises a number of factors:

1. cost of training users,
2. cost of generating Applications Packages⁷,
3. amortized cost of the equipment,
4. amortized cost of installation,
5. cost of maintenance, and
6. cost of support.

Assumptions

While all costs are expressed directly in dollars, most benefits are "irreducibles", i.e. they cannot be translated readily into monetary terms. For example, it is difficult to quantify the benefit of having consistently high quality drawings. However, having benefits rather than costs as "irreducibles" results in a "worst case" analysis, because only a few benefits are given credit while all foreseen costs are taken into account.

Increase in productivity of existing manpower is one benefit that lends itself to a more analytical treatment. The technique involves identifying activities that make up an engineering task, and obtaining data on man-hours needed for each activity. Based on this information, estimates of reduced man-hours required for activities affected by CADDs can be made.

Typically, activities necessary to produce the final version of an engineering drawing are:

- planning and preparation of the original,
- drafting of the original,
- approval, issue and distribution of the original,
- extraction of data from the drawing for wire lists, bills of materials, or numerically controlled (NC) machining - if applicable,
- planning and preparation for each revision,
- drafting of each revision, and

*CADDs considered in this paper are commercially available, stand-alone, multiple-station systems of the type offered by companies like Applicon Incorporated and Computervision Corporation.

- approval, issue and distribution of each revision.

Current CADDs equipment is best suited for activities like drafting and extracting data from drawings.

The benefit of CADDs to the overall job of producing the final version of a drawing is illustrated by a Time-Flow Diagram shown in Figure 1. The Time-Flow Diagram concepts are generalized and incorporated into the benefit-cost methodology.

Analysis

The derivation of the benefit-cost equations presented below is detailed in the Appendix.

The benefit B_i dollars per given period in producing N_i category i drawings on CADDs versus producing manually is given by:

$$B_i = C_D(nwH)f_iA(I_i-1)$$

where C_D is the average man-hour cost of a designer,

n is the number of work stations on CADDs,

w is the number of working shifts per day,

H is the number of single shift working hours in the period,

f_i is the fraction of CADDs system time allotted to category i drawings ($0 \leq f_i \leq 1$).

A is the average system availability factor, and

I_i is the ratio $S_{M_i}/(S_{S_i}/E)$

where S_{M_i} is the average man-hours needed for drafting a category i drawing (including revisions) and, where applicable, extracting data for wiring lists from the drawing manually,

S_{S_i} is the average man-hours needed using CADDs for drafting a category i drawing (including revisions) and, where applicable, extracting data for wiring lists from the drawing, and

E is the efficiency with which a designer operates CADDs.

FIGURE 1. TIME-FLOW DIAGRAM FOR GENERATING AN ELEMENTARY DIAGRAM

Overall benefit B dollars per period is thus:

$$B = \sum_i B_i$$

Overall cost C dollars per period is made up of a number of specific cost factors:

$$C = C_T + C_{AP} + C_E + C_I + C_M + C_{SP}$$

where C_T is the cost of training designers to operate CADDs,

C_{AP} is the cost of generating Application Packages,

C_E is the amortized cost of the CADDs equipment,

C_I is the amortized cost of CADDs installation,

C_M is the cost of equipment maintenance, and

C_{SP} is the cost of user support.

All the above cost factors are in dollars per period.

If C' is the cost per terminal-hour of a CADDs, where

$$C' = \frac{C}{nwH}$$

then, the overall net gain G_i dollars per period if N_i category i drawings are produced on CADDs versus manually is:

$$G_i = C_D(nwH)f_i \left[A(I_i-1) - \frac{1}{U} \frac{C'}{C_D} \right]$$

where U is the system utilization factor given by:

$$U = \sum_i f_i$$

Thus, net gain G_i is positive only if

$$I_i > \frac{1}{UA} \frac{C'}{C_D} + 1 \approx \frac{C'}{C_D} + 1$$

since both U and A have values close to one.

Since the terminal-hour cost C' for a CADDs can be estimated, the above expression can be used to determine which application, if implemented on CADDs, will yield a positive net gain G_i .

Overall net gain G dollars per period is:

$$G = \sum_i G_i$$

The value of overall net gain G at each stage of the CADDs implementation phase will vary and will depend on the activities at that stage.

The average number N_i of category i drawings produced in the period is given by:

$$N_i = (nwH)f_iA(E/S_{S_i})$$

Also, the number of designers P_i needed to produce N_i drawings is given by:

$$P_i = (nw \frac{H}{H'}) f_i A \left[\frac{M_{S_i}}{(S_{S_i}/E)} + 1 \right]$$

where H' is the average number of hours worked per designer in the period, after taking into account vacation and sick leave, and

M_{Si} is the average man-hours needed for planning, preparation, approval, issue and distribution of a category i drawing produced on CADDs.

Parameters w , H and H' are known, and A , E , M_{Mi} and S_{Si} can be estimated. The above two equations therefore may be used:

1. to determine the number of designers P_i needed to produce N_i drawings, or alternatively, the number N_i drawings produced by P_i designers, and
2. to allocate terminal time necessary to produce N_i drawings, or to assign the fraction f_i for a given number n of CADDs work stations.

In addition to showing that savings are possible with CADDs (i.e. G is positive), economic viability of CADDs can only be demonstrated if the savings are large enough to enable start-up costs to be recovered in a reasonably short time.

The cost recovery analysis is performed by computing benefit, cost and net gain at, for example, monthly intervals through various phases of CADDs implementation. The break-even point where all start-up costs are recovered is reached when the integrated net gain becomes positive.

The following assumptions regarding the preceding analysis should be noted:

1. the parameters used in the analysis are averages,
2. the work load on CADDs is distributed uniformly in time, and
3. the other important advantages of CADDs such as uniformity in drafting practices and consistent high quality ink drawings are not included in the computation of benefit.

APPLICATION OF THE TECHNIQUE

The benefit-cost analysis was applied to derive the cost justification for acquiring CADDs in the AECL drawing office. Data and assumptions made for the study, and the results are presented in the following example to illustrate the application of the technique.

Drawing Office Environment

AECL's drawing office at Sheridan Park, Mississauga, Ontario is responsible for producing design, construction and installation drawings, and associated documentation for the nuclear steam supply system of CANDU* nuclear power reactors.

The control and instrumentation group in the drawing office has about 80 design draftsmen and produces about 5000 drawings annually. In addition to generating drawings, the control and instrumentation draftsmen extract data from some of the drawings to produce inputs for computerized wiring list programs. Because of the nature of their work, this group was considered to have the potential of benefiting most from CADDs, and was therefore investigated in detail.

If CADDs were acquired, the design draftsmen currently involved with producing drawings and associated documentation will be trained to apply CADDs in their normal work. This approach of designers using CADDs directly, as opposed to designers submitting jobs to dedicated CADDs operators, is more efficient and has

been successfully tried in a research environment at AECL's Chalk River Nuclear Laboratories (CRNL).

Assumptions

Average man-hour data for manually producing block diagrams, control centre layouts, control panel layouts, elementary diagrams and flowsheets were obtained from the AECL drawing office (see Table 1). The annual drawing production is also shown in Table 1. Several other drawing types are also produced, but are not considered in this example.

Estimates of man-hours needed if the drawings were generated on CADDs are based on experience acquired at CRNL, as well as at other engineering organizations, and are made using the following assumptions:

1. The total man-hours spent by a designer in planning, preparation, approval, issue and distribution of a drawing are not affected by the use of CADDs.
2. With the availability of Application Packages**, man-hours needed for drafting an original drawing are reduced by a factor of two.
3. The capabilities of currently available CADDs reduce the man-hours needed for revisions by a factor of five.
4. Automatic extraction of data for wiring lists from a drawing is accomplished by special software built into CADDs. The designer enters some additional details not normally shown on the drawing, and initiates the program. It is assumed that about five to ten man-hours per drawing are needed for this activity.

A five work station CADDs (see Figure 2) is proposed, and the system is to be acquired on a five-year full pay out lease.

Additional assumptions necessary to compute benefit and cost are:

1. The CADDs implementation schedule is shown in Figure 3.
2. CADDs is operated on a single shift basis.

* CANDU - Canada Deuterium Uranium

**Application Packages are produced in-house to meet the specific needs of the applications. Based on our experience, each Package takes about 4 to 6 man-months to develop.

FIGURE 2. COMPUTER-AIDED DESIGN AND DRAFTING SYSTEM (CADDs)

TABLE 1. MAN-HOUR DATA FOR PRODUCING DRAWINGS MANUALLY AND ON CADDS

Category i	No. of Drawings Per Year	Method	Average Man-Hours per Drawing							TOTALS Man-Hours per Drawing					I_i with $E=1$
			Preparation of Original	Drafting of Original	Approval, Issue and Distribution of Original Extraction of Data for Wire Lists	Preparation of Revisions	Drafting of Revisions	Approval, Issue and Distribution of Revisions	$M_{M_i},$ M_{S_i}	S_{M_i}	S_{S_i}	Total Man-Hours per Drawing Manually	Estimated Man-Hours per Drawing on CADDS		
1. Block Diagrams	39	Manual	74.0	49.5	1	75	68.8	45.8	3	146.8	170.3	39.0	317.1	185.8	4.37
		CADDS	74.0	24.8	1	5	68.8	9.2	3						
2. Control Centre Layouts	20	Manual	37.5	112.5	1	-	60.0	180.0	12	110.5	292.5	92.3	403.0	202.8	3.17
		CADDS	37.5	56.3	1	-	60.0	36.0	12						
3. Control Panel Layouts	50	Manual	48.0	112.0	1	-	48.0	112.0	8	105.0	224.0	78.4	329.0	183.4	2.86
		CADDS	48.0	56.0	1	-	48.0	22.4	8						
4. Elementary Diagrams	625	Manual	19.3	13.0	1	85	21.5	26.3	4	45.8	124.3	21.8	170.1	67.6	5.70
		CADDS	19.3	6.5	1	10	21.5	5.3	4						
5. Flowsheets	28	Manual	43.3	29	1	-	19.1	28.7	4	67.4	57.7	20.3	125.1	87.7	2.84
		CADDS	43.3	14.5	1	-	19.1	5.8	4						

- The average number of single shift working hours per month is 162.5. When vacation leave and sick leave are considered, the average number of hours worked per designer per month is 141.7.
- The price of the proposed system is \$530,000, and the monthly lease payment is 2.2% of the price.
- Monthly cost of maintenance contract from the vendor is 0.9% of the system price. With the maintenance contract, a system availability factor of 97% is assumed.
- Cost of installation is \$25,000, which is amortized over a five-year period using straight-line depreciation accounting.
- Man-hour cost of designers is \$10.50. For this analysis, the System Supervisor's man-hour cost is also assumed to be the same as that of a designer. The man-hour cost of the Plotter Operator is \$7.05.
- Time spent by the System Supervisor and the Plotter Operator in support of CADDS through different phases of implementation is shown in Figure 4.
- The Application Package for each drawing category is developed by a designer under the guidance of the System Supervisor. The time spent on CADDS by these advanced users before the production phase is shown in Figure 5.
- Other designers will be trained as shown in Figure 5.

FIGURE 3. IMPLEMENTATION SCHEDULE FOR CADDS

FIGURE 4. MANPOWER REQUIREMENTS FOR CADDS - SYSTEM SUPERVISOR AND PLOTTER OPERATOR

FIGURE 5. MANPOWER REQUIREMENTS FOR CADDs - ADVANCED AND GENERAL USERS

11. In the production phase, all designers will apply the Application Packages to generate their designs on CADDs. Their efficiency E in using CADDs increases with experience as shown in Figure 6.

Selection of Applications

An application will yield net gain G_i if

$$I_i > \frac{C'}{C_D} + 1$$

The CADDs terminal-hour cost C' was estimated using the preceding assumptions and the following conditions (see Figure 3):

1. CADDs is in full production phase,
2. all users are trained, and
3. Application Packages are available.

The cost factors comprising CADDs terminal-hour cost C' are:

Equipment	\$14.35 per terminal-hour
Installation	\$ 0.51 per terminal-hour
Maintenance	\$ 5.87 per terminal-hour
Support	\$ 1.34 per terminal-hour

Therefore $C' = \$22.07$ per terminal-hour.

Since $C_D = \$10.50$ per man-hour, applications with

$$I_i > 3.10$$

will yield positive net gain.

FIGURE 6. CHANGE IN CADDs USER EFFICIENCY WITH EXPERIENCE

From Table 1, the following applications meet this requirement:

1. block diagrams,
2. control centre layouts, and
3. elementary diagrams

and are therefore selected for implementation on CADDs.

Allocating Terminal Time

The fraction f_i of the total terminal time for drawing category i can be assigned in a number of ways. In this example, the following conditions are assumed:

1. All block diagrams and control centre layouts are to be produced on CADDs. The rest of the system time is allocated to generating elementary diagrams.
2. Each drawing category will be produced on CADDs by designers specializing in the application.
3. These designers will only use CADDs for drafting and, where applicable, extracting data from the drawings (thus only integer values of P_i are used).

The terminal time allocation, number of designers and number of drawings produced for each drawing type are listed in Table 2.

TABLE 2. Applications Implemented on CADDs

Drawing Type	f_i	P_i	N_i per year
Block Diagrams	0.15	4	36
Control Centre Layouts	0.16	2	16
Elementary Diagrams	0.64	11	277

Cost Recovery Analysis

Calculating benefit and cost for each month from project initiation and using the implementation schedule of Figure 3 gives the results illustrated in Figure 7. Also shown is the integrated overall net gain through various phases of the CADDs implementation.

FIGURE 7. RESULTS OF COST-RECOVERY ANALYSIS

The following points should be noted:

1. Benefit remains zero until the start of production phase.
2. Cost continues to increase after project initiation, and peaks during the fourth month after CADDs acceptance due to the intense effort in training and Application Package development.
3. The "negative" benefit in the fifth month results from the loss of designer productivity since their efficiency E at applying CADDs is low.
4. The integrated overall net gain, when negative, indicates outlay, and when positive, indicates savings. The point at which integrated overall net gain becomes positive is the break-even point where the start-up costs are recovered. In this case, the break-even point is reached in under 18 months after system acceptance. Thereafter, savings continue to accumulate at a rate of over \$14,000 per month.

CONCLUSIONS

The methodology given in this paper is a practical technique for a quantitative benefit-cost analysis of CADDs in a drawing office environment. Specifically, this technique can be applied to:

1. derive the cost justification for acquiring a new CADDs facility,
2. determine the number of CADDs work stations necessary for a given organization,
3. determine the operating strategy for new or existing installations, and
4. monitor the utilization of existing installations.

An example using AECL data illustrated the application of the benefit-cost analysis technique. The results showed that acquiring a five work station CADDs for the drawing office is economically justified given the workload and the type of applications under consideration.

ACKNOWLEDGEMENTS

We wish to thank our colleagues at Sheridan Park for their cooperation and interest. In particular, we are indebted to A. Buresh for his enthusiastic support in providing us with the data needed for the analyses. We also thank the reviewers of this paper for their valuable comments and suggestions.

APPENDIX

Benefit-Cost Methodology

The simple principle used in the benefit-cost analysis is:

$$\text{Benefit (B)} - \text{Cost (C)} = \text{Net Gain (G)} \quad (1)$$

Benefit

Saving in man-hours, B_{Ti} , achieved by preparing category i drawings on CADDs is:

$$B_{Ti} = N_i \left[(M_{Mi} + S_{Mi}) - (M_{Si} + \frac{S_{Si}}{E}) \right] \quad (2)$$

where N_i is the average number of category i drawings produced in the period (e.g. one month);

M_{Mi} is average man-hours needed for planning, preparation, approval, issue and distribution of a category i drawing produced manually.

M_{Si} is average man-hours needed using CADDs for planning, preparation, approval and issue of a category i drawing.

S_{Mi} is average man-hours needed for drafting category i drawing and, where applicable, extracting data for wiring lists from the drawing manually,

S_{Si} is average man-hours needed using CADDs for drafting a category i drawing and, where applicable, extracting data for wiring lists from the drawing, and

E is designer efficiency in using CADDs ($0 \leq E \leq 1$).

Based on our experience, activities like planning, preparation approval, issue and distribution take similar man-power effort whether the task is done manually or using CADDs. Since,

$$M_{Mi} \approx M_{Si} \quad (3)$$

equation (2) becomes

$$B_{Ti} = N_i \left[S_{Mi} - \frac{S_{Si}}{E} \right] \quad (4)$$

The average number of category i drawings N_i can be expressed as:

$$N_i = \frac{\text{Number of terminal-hours available for category } i}{(\text{Average man-hours for drafting and data extraction on CADDs for a category } i \text{ drawing})}$$

$$\text{i.e.} \quad N_i = (nwh)f_i A(E/S_{Si}) \quad (5)$$

where n is the number of work stations on CADDs,

w is the number of working shifts per day,

H is the number of single shift working hours in the period,

A is the average system availability factor ($0 \leq A \leq 1$), and

f_i is the fraction of CADDs system time allotted to category i drawings.

Substituting equation (5) into equation (4), the saving in man-hours for a category i drawing in the period is:

$$B_{Ti} = (nwh)f_i A(I_i - 1) \quad (6)$$

$$\text{where} \quad I_i = \frac{S_{Mi}}{(S_{Si}/E)} \quad (7)$$

Since the existing designers are expected to operate CADDs in their normal work, the saving in

man-hours B_{T_i} translates into a financial saving of B_i dollars per period given by:

$$B_i = C_D(nwH)f_iA(I_i - 1) \quad (8)$$

where C_D is the average man-hour cost of a designer.

The number of CADDs users P_i needed to produce N_i drawings in the period is given by:

$$P_i = \frac{N_i \times (\text{Average man-hours to produce a category } i \text{ drawing on CADDs})}{\text{Number of hours worked in the period per designer}}$$

$$\text{or } P_i = \frac{N_i (M_{S_i} + S_{S_i}/E)}{H'} \quad (9)$$

where H' is average number of hours worked per designer in the period after taking into account vacation and sick leave ($H' < H$).

Substituting equation (5) into equation (9),

$$P_i = (nw \frac{H}{H'}) f_i A \left[\frac{M_{S_i}}{(S_{S_i}/E)} + 1 \right] \quad (10)$$

Parameters w , H and H' are known for a given period, and N_i or P_i , M_{S_i} and S_{S_i} should be available from the drawing office statistics.

Based on our experience, the other parameters may be estimated as follows:

1. S_{S_i} can be deduced using the following assumptions:
  - i. drafting time for an original is reduced by a factor of 1 to 3 on CADDs,
  - ii. automatic data extraction from a drawing takes 3 to 15 hours of the designer's time, and
  - iii. drafting time for revisions is reduced by a factor of 1 to 5 on CADDs.
2. The average availability factor A is about 0.97.
3. With Application Packages⁷ available, the CADDs user efficiency E improves rapidly with experience as shown in Figure 6.

Using these data in equations (5) and (10), P_i (if N_i is known) or N_i (if P_i is known), and f_i can be estimated for different values of n . The benefit B_i can be derived from equation (8).

Cost

The overall cost C dollars per period of CADDs is made up of a number of factors, and can be represented by:

$$C = C_T + C_{AP} + C_E + C_I + C_M + C_{SP} \quad (11)$$

where C_T is cost of training designers to operate CADDs,

C_{AP} is cost of generating Application Packages,

C_E is amortized cost of CADDs equipment,

C_I is amortized cost of CADDs installation,

C_M is cost of equipment maintenance, and

C_{SP} is cost of user support.

All the above cost factors are in dollars per given period.

Our experience has also shown that CADDs support can be provided by a System Supervisor and a Plotter Operator working on a part-time basis on CADDs. Therefore,

$$C_{SP} = jC_{SUP} + kC_{OP} \quad (12)$$

where C_{SUP} and C_{OP} are cost of the System Supervisor and the Plotter Operator in dollars per period respectively, and

j and k are fractions of the total working hours spent on CADDs by the System Supervisor and Plotter Operator respectively.

The CADDs cost C_i for category i drawings in dollars per period is:

$$C_i = \frac{f_i}{U} C \quad (13)$$

where U is system utilization factor given by:

$$U = \sum_i f_i \quad (14)$$

Net Gain

From equation (1), the net gain G_i in dollars per period for generating category i drawings on CADDs is:

$$G_i = B_i - C_i \quad (15)$$

Substituting equations (8) and (13) in (15)

$$G_i = C_D(nwH)f_i \left[A(I_i - 1) - \frac{1}{U} \frac{C}{nwH} \frac{1}{C_D} \right] \quad (16)$$

The term $C/(nwH)$ can be defined as cost per terminal-hour. Therefore, if

$$C' = \frac{C}{nwH} \quad (17)$$

then

$$G_i = C_D(nwH)f_i \left[A(I_i - 1) - \frac{1}{U} \frac{C'}{C_D} \right] \quad (18)$$

Equation (18) indicates that net gain G_i is positive if

$$I_i > \frac{1}{UA} \frac{C'}{C_D} + 1 \quad (19)$$

Since both U and A have values close to one, expression (19) can be approximated by:

$$I_i > \frac{C'}{C_D} + 1 \quad (20)$$

This expression can be used to select applications which, if implemented on CADDs, will yield positive net gain.

Overall net gain G of CADDs in dollars per period is the sum of net gains for all CADDs applications, i.e.

$$G = \sum_i G_i \quad (21)$$

REFERENCES

1. R.M. Dunn, "Computer Graphics: Capabilities, Costs and Usefulness", Computer Graphics, Vol. 7, No. 1, Spring 1973.
2. I.W. Cotton, "Cost-Benefit Analysis of Computer Graphics Systems", National Bureau of Standards (USA), Technical Note 826, April 1974.
3. R.L. Meyers, "How to Justify Acquiring an Interactive Graphics System", Electronic Packaging and Production, October 1976.
4. W.R. Laxon, "Selecting and Evaluating CAD Systems", Computer-Aided Design (UK), Vol. 9, No. 4, October 1977.
5. J. Potoczniak, M. Kosmin, R. Larkin, J. Callahan and R.M. Dunn, "Affordability of Computer Graphics for Planning Networks in DOD Program Management", Proceedings of the 3rd Annual Conference on Computer Graphics, Interactive Techniques and Image Processing, SIGGRAPH 76, July 1976.
6. S.H. Chasen, "Economic Principles for Interactive Graphic Applications", AFIPS National Computer Conference, California, May 1975.
7. R.R. Shah and G. Yan, "Development of Engineering Application Packages for Interactive Design of Electronic Systems", Fourth Man-Computer Communications Conference, Ottawa, May 1975.

ISSN 0067 - 0367

To identify individual documents in the series
we have assigned an AECL- number to each.

Please refer to the AECL- number when re-
questing additional copies of this document

from

Scientific Document Distribution Office
Atomic Energy of Canada Limited
Chalk River, Ontario, Canada
K0J 1J0

Price \$2.00 per copy

ISSN 0067 - 0367

Pour identifier les rapports individuels faisant
partie de cette série nous avons assigné
un numéro AECL- à chacun.

Veuillez faire mention du numéro AECL- si
vous demandez d'autres exemplaires de ce
rapport

au

Service de Distribution des Documents Officiels
L'Energie Atomique du Canada Limitée
Chalk River, Ontario, Canada
K0J 1J0

Prix \$2.00 par exemplaire