ECONOMICS
OF
CATHODIC PROTECTION

Presented at the

2nd International Conference and Exhibition
Cathodic Protection Theory and Practice
Stratford-Upon-Avon
Warwickshire, England
June 1989

by

H.A. Webster, P.Eng.
President
Corrosion Service Company Limited
Downsview, Ontario

TECHNICAL PAPER #11123

CORROSION
SERVICE

ECONOMICS OF CATHODIC PROTECTION

H.A. Webster, P.Eng., President

Corrosion Service Company Limited
369 Rimrock Road, Downsview
Ontario, Canada M3J 3G2

ABSTRACT

Cathodic protection is discussed in relation to the likelihood that its application will rest on economic considerations. Various methods are presented from the literature and a case is made for the use of the Equivalent Annual Cost Method together with several illustrations of its use.

ECONOMICS OF CATHODIC PROTECTION

Cathodic protection has an area of application that transcends the field of economic analysis. This area involves buried or immersed piping systems containing liquids that are environmentally hazardous or, if released, dangerous to human life. Cathodic protection is considered, in conjunction with high quality coatings, in the design stages of projects handling oil, natural gas, chemical or petrochemical feedstocks in buried or immersed systems.

The use of cathodic protection in situations permitting the assessment of alernatives will be more or less confined to the following general situations:

1. C.P. vs. selection of more resistant materials
2. C.P. vs. coating performance characteristics
3. C.P. vs. corrosion allowances
4. C.P. for planned life extension
5. C.P. vs. treating the environment (inhibitors, deaeration, etc.)
6. C.P. to extend economic life due to:
   a. unanticipated need for life extension
   b. unanticipated environmental changes
   c. design inadequacies due to ignorance of corrosion as a factor in material deterioration
   d. code requirements

When cathodic protection is identified as an economically viable engineering design procedure then alternative methods are available in the application of this technology which themselves may be examined using economic evaluation methods. For example, the choice between different permanent anode materials, the optimum spacing of groundbeds along a pipe, powered C.P. system vs. sacrificial anodes, the choice between various available sacrifical anode materials, powerline extension cost versus unconventional power sources, etc.

On functioning cathodic protection systems maintenance procedures and survey procedures can be improved by varying degrees of automation which in turn may require economic analysis procedures. There are numerous ways of making economic analyses of alternatives as there are numerous ways of approaching and solving an engineering problem. Alternative engineering solutions depend upon the imagination and skill of the engineers but are often assessed by management trained principally in the jungle of financial justification. The engineer must be able to assess his alternatives in terms understood by management. The instruction to "find a cheaper way" or "get maintenance costs down" are not engineering specifications.

Historically many corrosion engineers have made economic assessments of various choices that have presented themselves in the selection or sizing of cathodic protection equipment or materials. One of the earlier papers authored by Ray M. Wainwright [1] worked out a comparison of rectifier D.C. cable costs vs. cost of power losses in the cable. Kelvin's Economic Law suggests that the proper economic choice of cable size is that size which makes the sum of the annual cost of electrical losses in the cable and the annual fixed charges a minimum. Similar treatment can be undertaken by adding maintenance charges and power costs to the annual fixed charges on a cathodic protection system.

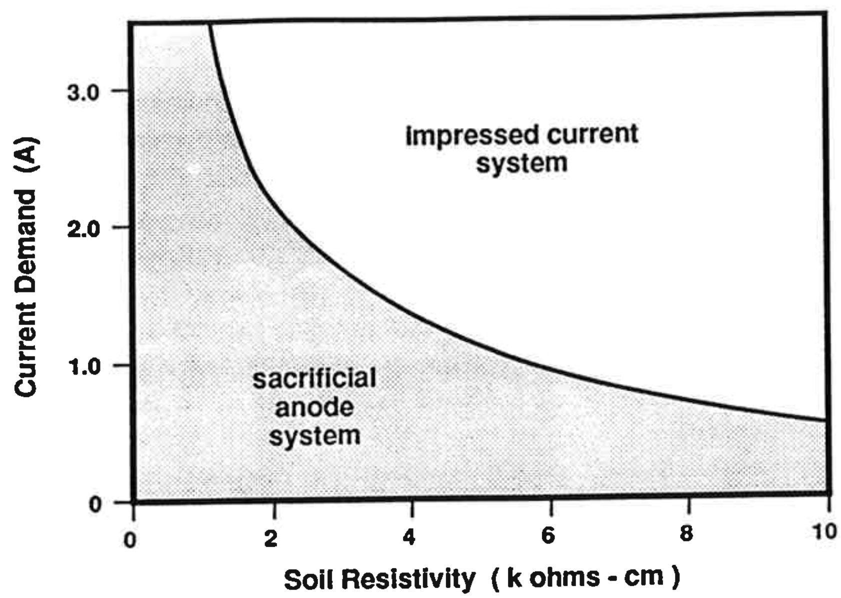
Where two alternative cathodic protection current sources are available their economies depend upon soil conditions and total current demands. This situation was treated by Baeckmann and Schwenk [2] who showed a boundary could be drawn between two domains on a graphical plot of current demand vs. soil resistivity (Figure 1).

Wranglen [3] produced a diagram shown in (Figure 2) which the cost of increasing coating perfection was added to decreasing cathodic protection costs to achieve a minimum cost. Others have related total installed costs of cathodic protection in £/mile to the cost of pipe replacement to show the cathodic protection is a miniscule fraction of these costs.

Sharpe [4] published a paper in 1955 entitled Economic Considerations in Pipe Line Corrosion Control in which he supported the premise that the costs of additional cathodic protection was so small that items of expense such as complete holiday inspection, ditch padding, rock shield, etc. could be dispensed with.

About two years ago much local (Toronto) effort was put into the promotion of zinc anodes for watermain protection. An "anode output - life" table showed the advantages of zinc over magnesium due to its inherently higher efficiency as an anode. Since it has a lower driving voltage the real advantage could only be determined by postulating a real application scenario. For this purpose a 24" bare watermain was chosen. At a current requirement of 1mA/sq.ft. the pipe would require 6.28 mA per lineal foot. Using the longest zinc anode available and 1000 Ω-cm soil, the pipe would require one anode every 3.18 feet. To protect a 1000 ft. of pipe, 314 zinc anodes would be required with a total weight of 3.77 tons. The life of this system would be 41.3 years (from the table). The magnesium anode (32 lb. 22" long) would protect 14.33 feet of pipe requiring about 70 anodes to protect the 1000' length of pipe with a total magnesium weight of a little over a ton (2240 lbs.). The number of excavations would be reduced to under 25% of those required for the zinc which would make it affordable to place the magnesium a little further from the pipe to improve current distribution. Looking at the cost per foot for this installation, the zinc anodes would cost about £22.50 each, making the cost of the metal £7065 plus about £50 per hole to install which would bring the cost up to £22.76 per foot. The magnesium anodes would cost £62.50 each plus £55 to install which in total would cost £8.22 per foot.

On the above basis the life of the zinc system is 2.39 times longer than that of the magnesium system but the costs are 2.7 times greater. If three 32 lb. magnesium anodes were placed in each excavation, the cost increase would only amount to £8.75 per foot for a total cost of £17.00 per foot and a life of nearly 52 years. Such comparisons require little skill in economic appraisal and are in frequent use by engineers. This assessement will be re-examined later using methods of economic appraisal which will be developed.



CATHODIC PROTECTION SYSTEM CHOICE

Von Baeckmann, W. and Schwenk, W., Handbook of Cathodic Protection, Portcullis Press Ltd., 1971, p.351

FIGURE 1

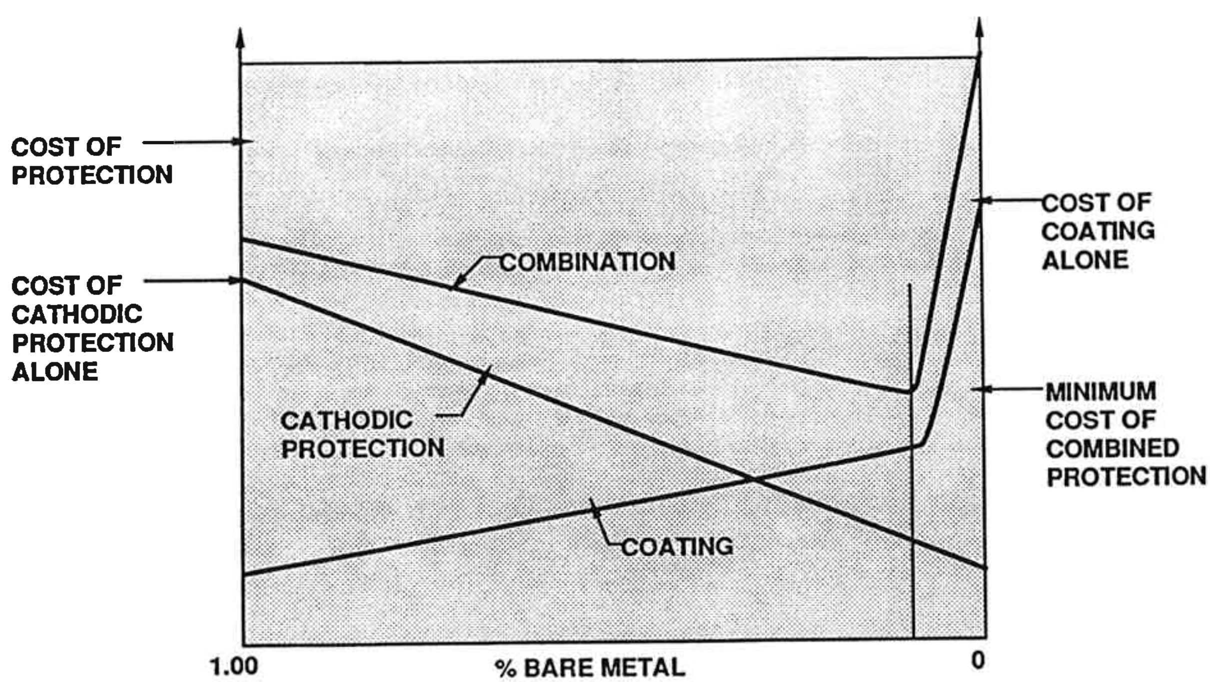


FIGURE 2

ECONOMIC DECISION MAKING

The engineer needs a simple method that he can remember in which he can develop confidence and is applicable to most engineering proposals which involve the improvement or replacement of existing equipment. This method must be flexible and its outcome easily understood and defended by the engineer. Basic data should be easily fed into the formula such that a range of alternatives can be easily evaluated and screened to reduce those alternatives submitted for management consideration. There is a method called "Equivalent Annual Cost" that fulfills the above requirement and will be used in all economic comparisons presented in this dissertation. A few concepts relating to the time value of money and the expectation of making a profit on invested capital must be reviewed.

THE TIME VALUE OF MONEY

A £ invested today at 10% interest will be worth £1.10 at the beginning of year two or £1.21 at the beginning of year three and so on. This growth is represented by a compound interest formula which relates the future worth of the investment in n years (or interest periods) represented by F_n to the present worth represented by P as follows:

$$F_n = P(1 + i)^n$$

where i is the interest rate expressed as a decimal and n is the number of the interest periods in the future for which F is to be determined — Eqn. 1

$$\frac{F_n}{P} = (1 + i)^n$$

which is called the ***Single Payment Compound Amount Factor***

If Eqn. 1 is rearranged:

$$P = F_n\left[\frac{1}{(1 + i)^n}\right] \qquad \text{Eqn. 2}$$

Eqn. 2 permits us to take some future sum of money and discount it back to the present.

$$\frac{P}{F_n} = \frac{1}{(1 + i)^n}$$

is called the ***Single Payment Present Worth Factor***

Using these two factors money can be compounded or discounted either into the future or from the future to the present. Future expenses or incomes can be discounted back in time to achieve a present value using a discount rate that truly represents the value of money.

THE PROFIT MOTIVE

A successful enterprise must have a real return on the money invested in the enterprise. This return is often expressed as yield, profit, rate of return or interest. The economist more often than not uses the term "interest" to mean expected rate of return whereas the engineer more often associates interest as being that amount that the bank demands when money is borrowed. There is little doubt that the bank looks upon the interest as an expected rate of return. The bank has a further expectation and that is, in addition to paying interest on a loan you must also repay the capital amount of the loan. It is important to note that no yield can be declared on an investment until the capital has been recovered.

PRESENT WORTH

Any future cash flow can be discounted back to the present using Eqn. 2 or by multiplying the cash flow by the ***Single Payment Present Worth Factor*** calculated using an appropriate interest rate expressed as a decimal and a value for n which relates to the point in time when the cash flow took place. Cash flows to which a negative sign is affixed are outgoing money whereas positive cash flows are income. If all cash flows are uniform both in magnitude and sign, it is not necessary to discount them individually for each period. The following equation will accomplish the calculation of present worth where A is the uniform annual cost or expense.

$$P = A\left[\frac{(1+i)^n - 1}{i\,(1+i)^n}\right] \qquad \text{Eqn. 3}$$

where:

$$\frac{P}{A} = \left[\frac{(1+i)^n - 1}{i\,(1+i)^n}\right]$$

which is called the ***Uniform Series Present Worth Factor***

If the equation is rearranged with a substitution from Eqn. 1 we can determine the size of an annual payment required to create a specified future amount at any time in the future at any chosen interest rate. This equation is shown below.

$$A = F_n \left[\frac{i}{(1+i)^n - 1}\right] \qquad \text{Eqn. 4}$$

where:

$$\frac{A}{F_n} = \left[\frac{i}{(1+i)^n - 1}\right]$$ is called the ***Sinking Fund Deposit Factor***

Rearrangement of Eqn. 4 permits the calculation of the future amount that can be expected with the investment of a uniform annual payment for a prescribed period of time at a prescribed interest rate.

$$F_n = A \left[\frac{(1+i)^n - 1}{i}\right] \qquad \text{Eqn. 5}$$

where:

$$\frac{F_n}{A} = \left[\frac{(1+i)^n - 1}{i}\right]$$ is called the ***Uniform Series Compound Amount Factor***

If two projects are contemplated, having equal lives, the calculation of the present worth of each project make them easy to compare. This comparison is invalid if the projected useful life of each project differs.

CAPITAL RECOVERY

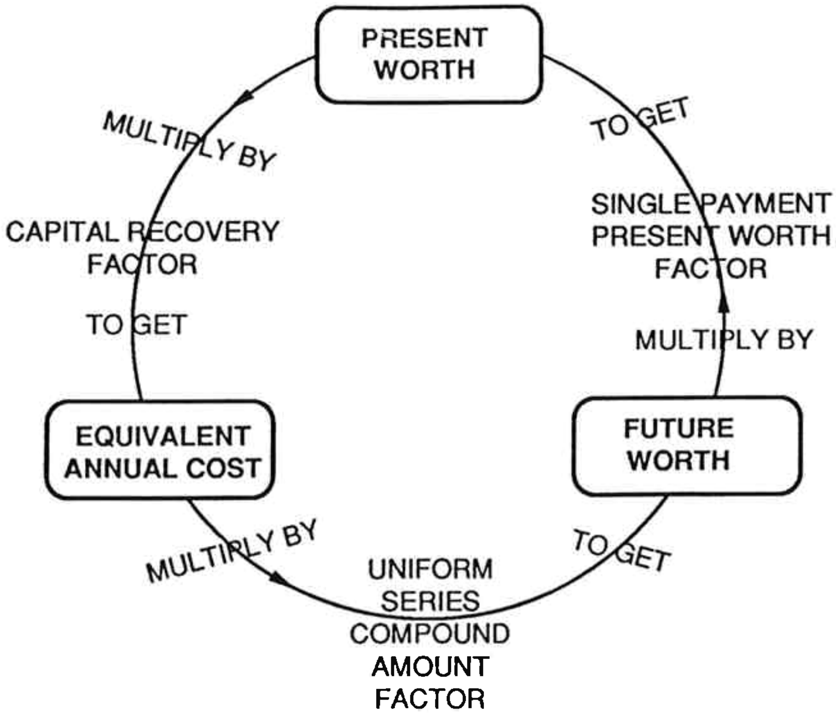
The sinking fund equation (Eqn. 4) determines the size of an equal annual payment that when invested at some interest rate will provide a specified future sum.

$$A = F_n \left[\frac{i}{(1+i)^n - 1}\right]$$

If we substitute $P(1 + i)^n$ for F_n (from Eqn. 1), we get:

$$A = P \left[\frac{i(1+i)^n}{(1+i)^n - 1}\right] \qquad \text{Eqn. 6}$$

$$\frac{A}{P} = \left[\frac{i(1+i)^n}{(1+i)^n - 1}\right]$$ which is called ***The Capital Recovery Factor***


PRESENT WORTH
TO GET
SINGLE PAYMENT PRESENT WORTH FACTOR
MULTIPLY BY
FUTURE WORTH
TO GET
UNIFORM SERIES COMPOUND AMOUNT FACTOR
MULTIPLY BY
EQUIVALENT ANNUAL COST
TO GET
CAPITAL RECOVERY FACTOR
MULTIPLY BY

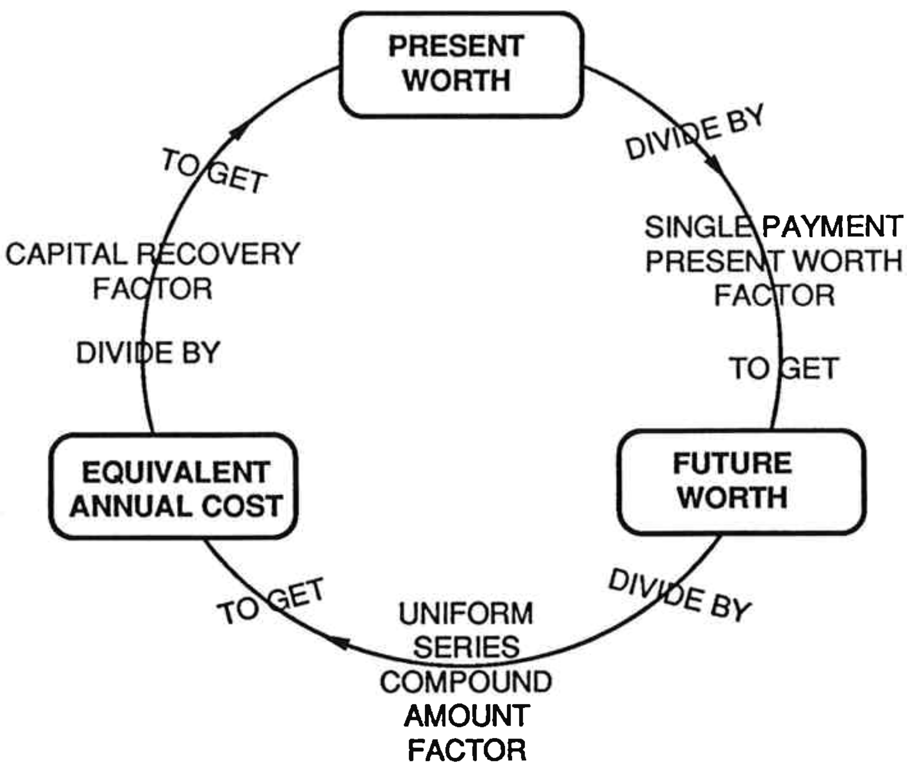

PRESENT WORTH
DIVIDE BY
SINGLE PAYMENT PRESENT WORTH FACTOR
TO GET
FUTURE WORTH
DIVIDE BY
UNIFORM SERIES COMPOUND AMOUNT FACTOR
TO GET
EQUIVALENT ANNUAL COST
DIVIDE BY
CAPITAL RECOVERY FACTOR
TO GET

FIGURE 3

which allows us to calculate the size of the equivalent annual payment that will recover our initial capital outlay if invested for a prescribed number of years at a prescribed interest rate. If the value of n is equal to the life of a project then the amount of the original outlay is in hand at the end of the project life to repeat the project if so desired. This annual payment then can fund a project in perpetuity. If this payment is calculated for two competing projects then it will be most useful in making economic comparisons since it is independent of project life. Other costs may occur such as maintenance and operating costs and these will have to be discounted back to the present and included in P before multiplying by the Capital Recovery Factor. We have therefore an Equivalent Annual Cost method for comparing competing projects whether their lives are equal or not.

At this juncture it should be noted that only Eqns. 2, 5 and 6 need be used since all the other equations are their reciprocals. This is shown graphically in Figure 3.

TAXES AND DEPRECIATION

Nearly all large expenditures for equipment are capitalized; that is they are held as an asset on the company books and depreciated in some manner in recognition of the fact that through wear and tear or obsolescence the value of the asset has diminished. Depreciation is considered an expense item but in reality it is a book entry only since it very seldom occurs that money actually leaves the company in the manner of other expense items. From a tax viewpoint depreciation is an allowable expense even though the money remains in the hands of the company. This results in a reduction of profits tax which could be considered as a positive cash flow. Although from the viewpoint of the application of economic analysis to cathodic protection schemes, which are deemed to be maintenance items, depreciation should not be a factor from a tax viewpoint. The subject will however be reviewed briefly.

A sinking fund can be set up to provide for the eventual replacement of a deteriorating asset. The payments into this fund can be assumed to represent the depreciation of the asset. Such a course of action is seldom actually undertaken. If a good approximation of the lifetime of, say, a piece of machinery could be determined then it would seem reasonable to write down the original cost of the machine over this period on a straight line basis to some terminal salvage value. In the U.S.A. the ***Sum of Digits*** method is popular. In this method the number of years over which the item is to be depreciated is determined and the year digits are summed. The first years depreciation is equal to the total number of years divided by the sum of the year's digits. For example, say the life for depreciation purposes is 5 years. The sum of year's digits is 15. First year depreciation is 5/15, second year 4/15 and so on. In Canada and U.K. the depreciation schedule permitted by the tax department is called ***Constant Percentage of Depreciated Balance***. Here a fixed percentage is taken off the original cost of the asset at the end of year one and thereafter off the depreciated balance. As can be seen this method will never completely depreciate the asset. Both the Sum of Digits and Constant Percentage of Depreciated Balance method result in rapid early write off of an asset. Some economists refer to these methods when graphically presented as "Curves of

Second Hand Value" since these methods of depreciation are more applicable to items that are "styled out" rather than those in the real world of industrial enterprise. An automobile is typical of such a property. If it were not for style, it would be more appropriate to write down an automobile on a straight line basis to some salvage value over a 12-year period. In Canada a company owned automobile is depreciated 30% of its cost in the first year giving a fair approximation of its second hand value.

The tax department permits different rates of depreciation for different classes of assets. It is common practice to lump all assets attracting the same depreciation rates into a single fund and then depreciate the fund. Accountants look upon depreciation as a "tax shield" and regard tax savings as a positive cash flow.

ESTABLISHMENT OF A SUITABLE RATE OF RETURN

There are usually more opportunities to invest capital than capital available for investment. Of these opportunities the one giving the greatest return on investment will be chosen if the proposition is not too risky. If it is not invested then a loss has been taken equivalent to the amount that could have been earned in the best available investment. The expected rate of return in a business is always greater than prime bank lending rates since nearly all businesses borrow their operating funds and still manage to make a profit. The minimum rate of return should equal the bank borrowing rate plus the historical rate of return on equity. An estimate of this rate of return should be solicited from management. If doubt exists as to what interest rate to use in economic comparisons, do the comparisons using a range of interest values and let management pick the result they like best.

EXAMPLES

For any initial expenditure for cathodic protection, it will be assumed that annual charges will include a Capital Recovery Factor that will accumulate sufficient funds to recover the original capital for replacement of the protection system at the end of its useful life. Maintenance items, if any, will be reduced back to Present Worth using the Present Worth Factor and included in the initial outlay prior to the application of the Capital Recovery Factor. For economic comparison purposes it is considered that cathodic protection systems are a maintenance expense when applied to buried or submerged systems and hence are not capitalized and depreciated from a tax viewpoint.

Example No. 1

An economic decision must be made whether to continue leak repairs on a watermain system, cathodically protect the piping or to replace with a P.V.C. piping system. The costs will be considered for a 1 km length of pipe experiencing 3 leaks per km. Although it is known from cumulative leak history curves that the leak rate will increase exponentially, the assumption will be made in this analysis that the leak rate will remain constant. The leaks cost $5000 each to repair. The fact that leak repair in the future could be more costly is ignored.

Cathodic protection using magnesium anodes designed for a 20 year life will reduce repairs by 95%. The initial installed cost of this system is $50,000. The Cathodic Protection System will not require maintenance. Replacing 1 km of main with P.V.C. will cost $400,000. For comparison the P.V.C. main is expected to have a 40 year maintenance free life. The expected return on money is 12%.

(a) Repair Leaks:

Equivalent Annual Cost = Annual Cost of Repair
= $15,000

Note: Uniform Series Present Worth Factor x Capital Recovery Factor = 1

(b) Install C.P. - 20 year life: Interest at 12%

Equivalent Annual Cost = Present Worth x Capital Recovery Factor
+ 5% cost of leak repair
= $50,000 x 0.13388 + $750
= $6,694 + $750
= $7,444

(c) Replace Pipe with P.V.C.- 40 year life: Interest at 12%

Equivalent Annual Cost = Present Worth x Capital Recovery Factor
= $400,000 x 0.12130
= $48,520

It is clear that the C.P. system is the least costly (most cost effective) than the other two alternatives. The equivalent annual cost of this system is the cost of borrowing sufficient money to fund the perpetual replacement of anodes. No allowance is made for inflation since these figures are produced for economic comparison only. If the equivalent annual cost excess shown in the leak repair analysis were applied to the borrowing costs a substantial inflation factor would be covered.

There is little doubt that the pipe replacement will be a capital expenditure and can be depreciated at 6% (Under Canadian Tax Laws). If the pipe replacement alternative was credited with tax savings then so also would the repair and cathodic protection alternatives. In Alternatives A and B, the Equivalent Annual Cost would be reduced by a factor of 0.5 to allow for the fact that the annual costs would be paid for out of before tax revenue and the corporate tax rate is 50% of net earnings. The Equivalent Annual Cost of Alternative C would be multiplied by the Depreciation and Tax Factor:

$$D = 1 - rd\left[\frac{(1+i)}{(i+d)}\right]$$

where $i = 0.12$
$d = 0.06$ (depreciation)
$r = 0.5$ (taxes)

$$= 0.813$$

It is not necessary to complete this analysis since it is obvious that it would not affect the original outcome by any significant amount. If the "life" of the pipe were changed from 40 years to infinity, the Capital Recover Factor would change from 0.12130 at 40-years to 0.12000 at infinity which again would have little effect on the outcome of the analysis. Pipe replacement could only be supported if it were felt that cathodic protection could not prevent pipe breaks owing to the already greatly deteriorated condition of the pipe. An analysis could be done to determine the number of breaks per km that would have to be repaired before this analysis would support pipe replacement. The Equivalent Annual Cost of Alternative A would have to equal that of Alternative C.

Present Worth = $48,520

If this dollar value is divided by the cost of a leak repair, it represents a leak rate of 9.7 leaks per km per year. At this point repair and replacement costs are equivalent. It must be remembered that leaks and piping breaks have many effects that transcend repair cost alone. Loss of water, loss of service to the customer, cave-ins and washouts requiring extensive repair, public liability due to motor or pedestrian accidents due to unsafe road conditions are among the expected possibilities. Management will include an assessment of these possibilities together with the economic analyses when making decisions.

Example No. 2

In this example please refer to the discussion on zinc and magnesium earlier in this paper. Here we are comparing systems that have different costs and different anticipated useful lives. The Equivalent Annual Cost method is eminently suitable to decide on the most economical choice. Again we asume that our expected rate of return on money is 12%. Three alternatives are being examined:

(a) A zinc system costing £22765 installed with a life of approximately 40 years

(b) A magnesium system costing £8225 installed with a life of 17 years

(c) A magnesium system costing £16975 installed with a life of 50 years

(a) Zinc Anodes - 40 year life: Interest at 12%

Equivalent Annual Cost = Present Worth x Capital Recovery Factor
= £22765 x 0.12130
= £2761

(c) Magnesium Anodes - 17 year life: Interest at 12%

Equivalent Annual Cost = Present Worth x Capital Recovery Factor
= £8225 x 0.14046
= £1155

d) Magnesium Anodes - 50 year life: Interest at 12%

Equivalent Annual Cost = Present Worth x Capital Recovery Factor
= £16975 x 0.12042
= £2044

The advantage suggested in the previous analysis is confirmed. Even though alternative (B) is far cheaper there is no guarantee that these anodes can be installed for the same price 17 years hence. Alternative C would be preferred if funds were available.

It can be seen that the high cost of excavating has a great bearing on the choice of anode. Husock [5] did an interesting analysis in which he plotted equivalent annual costs against installation costs for three different weights of anodes making various assumptions on current output.

Example No. 3

Cathodic protection is contemplated for a pipeline. This can be accomplished by the use of sacrificial anodes, rectifiers and groundbeds or a combination of both. The estimated costs and lives of the alternatives are as follows: (interest rate 12%)

(A) Sacrificial Anodes $150,000 installed, life 10 years

(B) Rectifier and groundbeds $120,000 installed, life 20 years. Estimated annual operating and maintenance charges $5,000/year

(C) Combination Rectifier and Anode System. Rectifier and groundbeds $60,000 annual maintenance and operating costs $2,500/year, life 20 years
Sacrificial anodes $7,000 installed cost, life 10 years

(a) Sacrificial Anodes:

Equivalent Annual Cost = Present Worth x Capital Recovery Factor
= $150,000 x 0.17698
= $26,547

(b) Rectifier and Groundbeds:

Equivalent Annual Cost = Present Worth x Capital Recovery Factor + Annual Charges

Equivalent Annual Cost = $120,000 x 0.13388 + $5,000
= $16,065 + $5,000
= $21,065

(c) Combination Rectifier and Anode System:

Equivalent Annual Cost = \$60,000 x 0.13388 + \$2,500 (Rectifier & Groundbeds)
= \$8,032 + \$2,500
= \$10,532

Equivalent Annual Cost = \$75,000 x 0.17698 (Sacrificial Anodes)
= \$13,273

Total Equivalent Annual Cost of Combined System = \$23,805

This analysis indicates that the Rectifier and groundbed system is the economic choice. Using the same techniques evaluation can be made on the basis of groundbed materials installed for different lives, conventional versus deepwell groundbeds, spacing and sizing of rectifiers, etc. The requirement is that the cost estimate for each alternative is accurately known. For example conventional groundbeds may required negotiation of an easement with its attendant cost whereas a deepwell groundbed could be installed on an existing right-of-way. Optimum rectifier spacing may require the building or extension of power lines or the use of expensive alternative power sources the cost of which would weigh against the economic effects of non uniform current distribution.

Example No. 4 (Adapted from Ref. No. 6)

Five anode designs for the protection of an offshore platform are available for a range of projected lives as shown:

(a)	2 year magnesium anode design	\$ 3,896
(b)	3 year magnesium anode design	\$ 5,670
(c)	5 year magnesium anode design	\$ 8,085
(d)	8 year magnesium anode design	\$ 11,920
(e)	10 year magnesium anode design	\$ 15,430

Which design will be the most cost effective if interest rates are 8%? 10%? 12%? 20%?

Interest at 8%

Proposal	Cost	x	Capital Recovery Factor	=	Equivalent Annual Cost
(a)	\$3,896	x	0.561 (2 yr. life)	=	\$2,185
(b)	\$5,670	x	0.388 (3 yr. life)	=	\$2,199
(c)	\$8,085	x	0.250 (5 yr. life)	=	\$2,021
(d)	\$11,920	x	0.174 (8 yr. life)	=	\$2,074
(e)	\$15,340	x	0.149 (10 yr. life)	=	\$2,285

The 5 year design should be chosen.

Interest at 10%

Proposal	Cost	x	Capital Recovery Factor	=	Equivalent Annual Cost
(a)	$3,896	x	0.576 (2 yr. life)	=	$2,244
(b)	$5,670	x	0.402 (3 yr. life)	=	$2,280
(c)	$8,085	x	0.264 (5 yr. life)	=	$2,134
(d)	$11,920	x	0.187 (8 yr. life)	=	$2,229
(e)	$15,340	x	0.163 (10 yr. life)	=	$2,500

The 5 year life is preferable.

Interest at 12%

Proposal	Cost	x	Capital Recovery Factor	=	Equivalent Annual Cost
(a)	$3,896	x	0.592 (2 yr. life)	=	$2,306
(b)	$5,670	x	0.416 (3 yr. life)	=	$2,358
(c)	$8,085	x	0.277 (5 yr. life)	=	$2,239
(d)	$11,920	x	0.201 (8 yr. life)	=	$2,395
(e)	$15,340	x	0.177 (10 yr. life)	=	$2,715

Again the 5 year life is preferable.

Interest at 20%

Proposal	Cost	x	Capital Recovery Factor	=	Equivalent Annual Cost
(a)	$3,896	x	0.655 (2 yr. life)	=	$2,551
(b)	$5,670	x	0.475 (3 yr. life)	=	$2,693
(c)	$8,085	x	0.334 (5 yr. life)	=	$2,700
(d)	$11,920	x	0.261 (8 yr. life)	=	$3,111
(e)	$15,340	x	0.239 (10 yr. life)	=	$3,666

Here the 2 year life should be chosen.

If these alternatives had been examined at 13% interest rate proposal (b) would have been cheapest. Proposal (a) will be favoured at interest rates above 14%. At a 4% interest rate proposal (d) has the edge. We can conclude something we already suspect, when interest rates are high or we expect large returns on our capital then large long term investments have no merit over small investments repeated frequently.

Example No. 5

Rehabilitation of a reinforced concrete parking structure 10,000 sq. metres - 30% delaminated.

Proposal (a)	Repair delaminations at £50 per sq. metre	£400,000
	Membrane at £48 per sq. metre	£130,000
	Repair to be repeated every 7 years	£400,000
	Membrane requires only 30% replacement	£39,000
Proposal (b)	Repair delaminations	£400,000
	Cathodic Protection	£210,000
	Cathodic Protection maintenance and remote monitoring	£750 per year
	Partial replacement CP system in 12 yrs.	£105,000

Proposal (a) 12% interest, life 7 years

Equivalent Annual Cost = Present Worth x Capital Recovery Factor
Present Worth = £400,000 + £130,000 + £439,000 x Single Payment Present Worth Factor (7 years)
= £530,000 + £439,000 x 0.45235
= £530,000 + £198,581
= £728,581

Equivalent Annual Cost = £728,581 x 0.21912
= £159,646

Proposal (b) 12% interest, life 12 years

Equivalent Annual Cost = Present Worth x Capital Recovery Factor
Present Worth = £610,000 + £105,000 + £439,000 x Single Payment Present Worth Factor (12 years)
= £610,000 + £105,000 x 0.25668
= £610,000 + £26,951

Equivalent Annual Cost = £610,000 x 0.12 + £26,951 x 0.16144 + £750
= £73,200 + £4,350 + £750
= £78,300

This analysis gives the cathodic protection alternative a clear advantage.

A few closing comments are in order. Equivalent Annual Cost is a useful technique for economic justification of cathodic protection alternatives but is by no means all there is to financial justification. There are many textbooks available that cover this subject in great detail a few of which are mentioned in the bibliography. There are also many considerations that cannot be reduced to pounds and pence such as goodwill, good (or poor) public relations and that "evasive eel" the slim possibility of catastrophe. All of these factors must be considered by anyone responsible for final decisions. The Equivalent Annual Cost Method is easy to use and its outcome is easily understood. Although this paper did not go deeply into tax implications they can be effectively handled by this method. As can be seen in the examples, changes in estimates or rates of return can be easily accommodated giving the engineer a firmer footing when discussing alternatives with management.

n	C.R.F. (A/P)	n	C.R.F. (A/P)	n	C.R.F.(A/P)
1	1.1200	11	0.16842	25	0.12750
2	0.59170	12	0.16144	30	0.12414
3	0.41635	13	0.15568	35	0.12232
4	0.32923	14	0.15087	40	0.12130
5	0.27741	15	0.14682	50	0.12042
6	0.24323	16	0.14339	60	0.12013
7	0.21912	17	0.14046	70	0.12004
8	0.20130	18	0.13794	80	0.12001
9	0.18768	19	0.13576	90	0.12000
10	0.17698	20	0.13388	∞	0.12000

Table No. 1: Capital Recovery Factors at 12% Interest for Year n

n	S.P.P.W.F.(P/F)	n	S.P.P.W.F.(P/F)	n	S.P.P.W.F.(P/F)
1	0.89286	11	0.28748	25	0.05882
2	0.79719	12	0.25668	30	0.03338
3	0.71178	13	0.22917	35	0.01894
4	0.63552	14	0.20462	40	0.01075
5	0.56743	15	0.18270	50	0.00346
6	0.50663	16	0.16312	60	0.00111
7	0.45235	17	0.14564	70	0.00036
8	0.40388	18	0.13004	80	0.00012
9	0.36061	19	0.11611	90	0.00004
10	0.32197	20	0.10367	∞	0

Table No. 2: Single Payment Present Worth Factors at 12% Interest for Year n

REFERENCES

1. Wainwright, Ray M. Corrosion, Vol. 9, No.9, p.325 (1953).

2. Baeckmann, W.V., Schwenk, W. Handbook of Cathodic Protection, Portcullis Press Ltd., Redhill, p.351 (1975).

3. Wranglen, G. An Introduction to Corrosion and Protection of Metals, Butler and Tanner Ltd., Frome and London, p.168 (1972).

4. Sharpe, L.G., Corrosion, Vol.11, p.227t (1955).

5. Husock, B. Materials Protection, Vol. 7, No. 6, p.33 (1968).

6. Park, Ben. D. NACE Corrosion 71, Paper No. 104.

BIBLIOGRAPHY

Birkett, C., The Economic Choice - A Method for Decision, Paper presented at NACE Canadian Eastern Regional Meeting, Nov. 1960.

Watson, T.R.B., Economic Evaluation of Corrosion Control, Paper presented to NACE Canadian Region Western Conference, Feb. 1980.

Taylor, G.A., Managerial and Engineering Economy, D. Van Nostrand Company Inc., Princeton, N.J., U.S.A. (1964)(1965)(1968).

Young, C.R., An Introduction to Engineering Economics, The University of Toronto Press (1949).

Verink, E.D., A Simplified Approach to Corrosion Economic Calculations, NACE Corrosion 82, Paper No. 79.

NACE R.P.02-72, Recommended Practice Direct Calculation of Economic Appraisal of Corrosion Control Measures.