A TECHNIQUE TO DETERMINE THE OPTIMUM REPLACEMENT CYCLE FOR CAPITAL EQUIPMENT

By T. J. MURRAY

South African Sugar Association Experiment Station, Mount Edgecome 4300

Abstract

A technique that has been developed to determine the optimum replacement cycle for capital machinery is described. The technique allows replacement cycles for individual machines and general policy to be evaluated.

Introduction

The costing of mechanized agricultural operations is generally based on the principle of linear depreciation of the value of equipment. Repairs and maintenance costs are expressed as a proportion of the initial investment. This principle involves an assumed effective life cycle which is usually based on personal judgment and apparent state of repair of the equipment. These criteria alone cannot justify replacement because the escalation of machinery and non-equity finance costs also have to be considered.

A technique developed to determine the optimum replacement cycle for vehicles and a method of evaluating a particular case are discussed in this paper.

Replacement Policy

The replacement of machinery should be based on economic considerations rather than the physical condition of the machine. Options to be considered are:

- Continued use of the old machine.
- Purchase of a new machine and replacement of the old.
- Hiring a contractor to carry out all or part of the operation.
- Determining the number and size of machines required to do the job most economically (Peterson & Milligan[6]).

Only the first two options are discussed here. When considering whether or not to replace vehicles one should either maximise profits generated by capital equipment or minimise costs. The purchase and maintenance costs of agricultural machinery are spread over a number of years. The varying value of money and its earning potential in alternative investments should be considered.

The technique described here aims at reducing to a minimum the total cost of a vehicle's life cycle in present day terms. The difficulty of specifying a vehicle's activities accurately enough to make a realistic estimate of its profitability, justifies reducing costs to a minimum. This implies maximum profits.

The Model

The model takes only age-related costs into account to avoid the insensitivity that might arise if other costs were included. Factors considered are:

Repair costs

Booysen and de Beer[4] assumed that repair costs for tractors are approximated by a linear distribution of 75% of the initial investment. Although this method is generally acceptable (Andsley & Wheeler[3]) for simple comparative costing, it is not sensitive enough for replacement decisions because it does not allow for changes in repair costs from year to year.

Either a function used by the ASAE,[5] where repair costs are expressed as a non-linear function of accumulated utilization, or average repair costs in present day values, for machines of different ages, should be used (see Table 1).

Trade-in value

Depreciation is the difference between the purchase price and the trade-in value. Residual farm value (RFV) data are obtained from ASAE[1] expressed as a function of age. Booysen and de Beer[4] assume a linear decrease in residual value as age increases. Data from Mead and McGrouther[2] are used to relate age to the proportion of original value retained by a vehicle.[7] This results in the following expression:

$$RFV = 0{,}78\,(0{,}92)^n \qquad (1)$$

Where RFV is the fraction of original purchase price retained as a trade-in value after n years of age.

Desirable interest on investment

When discounting future expenditure to present day values, a value for interest rates is assumed. A comparison of investment alternatives with the different life spans of equipment is then possible. Generally the discount factor (DF) used to calculate the present value of a future annuity is given as:

$$DF = \frac{1-(1+r)^{-n}}{r} \qquad (2)$$

where r = rate of interest and n = duration of annuity in years. eg. R1.00 a year for 10 years is worth R6.71 at 8% interest now.

To calculate the present value of a future sum of money the factor (F) is given by

$$F = \frac{1}{(1+r)^n} \qquad (3)$$

eg.
R10 at 8% interest in 10 years time is worth R4,63 now.

Inflation

The inflation rate is the rate at which the capital required to purchase an asset escalates. Inflation affects the purchase price, repair costs and the residual value of equipment. If the inflation rate is g then the inflation factor (IF) for calculating the future cost of any item is given by:

$$IF = (1+g)^n \qquad (4)$$

where n is the period in years.

TABLE 1
Present day values of repair costs for a vehicle of different ages

Vehicle age (years)	1	2	3	4	5	6	7	8
Annual repair cost (R)	500	800	1 800	2 800	1 300	1 300	1 800	3 500

Only age-related costs should be considered.

Taxation

It is difficult for an individual farmer to assess the effects of taxation on machinery costs and consequently on his decision to replace equipment. It is much simpler for those who operate their farming undertakings as a company.

Assuming a company tax rate of 43% and that assets purchased are totally tax deductable in the year of purchase, and that the resale value is taxable in the year of resale, the company effectively pays only 57% of the purchase price, even though the tax benefits may occur at a different time of the year from the purchase and that a resale realizes only 57% of the resale value and the time between resale and taxation alters the value of the transactions.

All repair costs are tax deductable. Taxation plays a large role in determining the cost of operating a vehicle and consequently affects the replacement decision.

Discounted cash flow DCF)

Discounted cash flow is a technique to sum present and future expenditure or returns and to represent all transactions at present values for comparison. In a replacement analysis purchase price, repair costs, and resale can all be discounted to the present and summed to obtain a total cost of the life cycle of a vehicle in today's terms.

The discount factor used is in equation (3) but if inflation is to be taken into account then equation (3) must be modified to include details of equation (4) as follows:

$$IF = \left(\frac{1 + g}{1 + r}\right)^n \qquad (5)$$

where g = inflation rate and r = interest rate and n is the time in years (interest and inflation expressed as fractions).

Computations

A replacement policy should evaluate options. The first decision to be made is how often a vehicle should be replaced. To determine the life cycle that has the least cost, all present and future costs for different life spans have to be summed.[8] This is illustrated mathematically as follows:

$$TFC_n = 0{,}57\ C + \sum_{x=1}^{n}\left(M(x)D^{x-0,5} - 0{,}43d^{x}M(x)G^{x-0,5}\right) - 0{,}57T(n)D^{n} \ldots (6)$$

It is assumed that repair expenditure is incurred at mid-year and that tax concessions are effective from the year-end:

C = Capital value today

$m(x)$ = Repair cost in the xth year of the vehicle's life

$d = \dfrac{1}{1 + r}$

$G = 1 + g$

$T(n)$ = Trade value of a 'n' year old vehicle

$D = dG$

TFC_n is total future cost of a cycle of n years length and would be evaluated for cycles ranging from n = 1 year through n = 10 years.

The values of TFC_n represent the total cost of a cycle of 1 to n years length in present day terms. They are not directly comparable as they represent costs from cycles of different length. To compare these different cycles one can either sum all future TFC_n values to infinity as done by Stewart[8] or amortize the TFC_n values over n years. Each length of cycle would be expressed as an annual cost and cycles would therefore be comparable.

$$AMT = \frac{TFC_n r(1 + r)^n}{(1 + r)^n - 1} \qquad (7)$$

AMT is the annual mortgage repayment on a capital value of TFC_n over n years.

A computer programme called RPLMT has been written for the Hewlett Packard 41C programmable calculator to evaluate the various replacement cycles (see RPLMT in Appendix I).

RPLMT data relate to an average vehicle. This is therefore not a suitable basis for deciding whether a specific tractor should be repaired or replaced.

A second programme called SELL has been written to evaluate a specific case. The programme assumes that the vehicle to be purchased is an average vehicle and therefore uses information from RPLMT to evaluate the three options which are:

- Sell now.
- Sell in 1 year's time.
- Sell in 2 or more years' time.

To compare these three options, the total future costs for each option are evaluated assuming two complete cycles follow the vehicle under consideration.

Sell now

This option means selling now for the "as is" trade value

$SN = (1 + D^{n1})\ TFC_{n1} - 0{,}57\ T(now)$ ....(8)

where n_1 is the optimum cycle duration determined in RPLMT and T(now) is the as is trade value. SN is the capital value to be amortized over 2 x n1 years.

Sell in one year

This option involves repairing the vehicle and selling after a further year's use:

$S1 = (1+D^{n1})D\ TFC_{n1} - 0{,}57DT_1 + (1 - 0.43\ d(1+g)^{0'5})M$

where S1 is the total present day cost of repairing now for a cost of M rand then trading for T_1 (in present day value) and following with two cycles each of n1 duration. S1 would be amortized over 2 x n1 + 1 years.

Sell in 2 years

This option allows the vehicle to be repaired now, and then once more and sold thereafter.

$$S2 = (1+D^{n1})D^2TFC_{n1} - 0{,}57D^2T_2 + (1 - 0{,}43d(1+g)^{0'5})M + (1 - 0{,}43d^2(1+g)^{1'5})M_2D^2$$

where S2 is the total present day cost of keeping the vehicle two more years then selling. T_2 is the trade value of a vehicle two years older than at present; M_2 is the expected repair costs in the second year from now. S2 would be amortized over 2nl + 2 years.

The least expensive of these three options should be taken.

Examples of the application of programmes RPLMT and SELL are given in Appendix II.

Conclusion

A simple yet thorough technique has been developed which provides a means for evaluating the least cost replacement cycle. It is based on average repair costs obtained from the operator and thus reflects the level of management or reliability of the machine. Provision has been made for the analysis of a particular case on the assumption that the vehicle concerned would be replaced with one that behaves as an average vehicle would. This technique allows the evaluation of a different type of machine and is applicable to any capital item that requires replacement.

REFERENCES

1. Agricultural Engineers Yearbook. (1979). St Joseph, Michigan: *ASAE.*
2. Agricultural Machinery Dealers Digest. (1981). Randburg: Mead and McGrouther.
3. Andsley, and Wheeler, J. (1978). The annual cost of machinery calculated using actual cash flows. *J Agric Engng Res* **23:** 189–201.
4. Booysen, S. S. and de Beer, A. G. (1977). Machinery selection by costing analysis. *SASTA Proc* **51:** 12–15.
5. Murray, T. J. (1981). Unpublished research data.
6. Peterson, C. L. and Milligan, J. H. (1976). Economic life analysis for machinery replacement decisions. *Trnas Am Soc Agric Engrs* (19) 5: 819–822.
7. Simms, E. A. (1976). Machinery replacement; Economic considerations. *WIST Proc* 32–26.
8. Stewart, G. E. (1979). Personal communication.

APPENDIX 1

Program listings for "RPLMT" and "SELL" as they are applicable to a HEWLETT PACKARD 41C programmable calculator

```
LBL RPLMT
CLA
"(ENTER) x, r, k, Tax"
PROMPT
STO 16
RDN
STO 13
RDN
1
+
1/X
STO 11
RDN
1
+
STO 00
RCL 11
*
STO 12
LBL 02
1.00001
STO 19
"CYCLE"
PROMPT
STO 15
ENTER
1 000
÷
ST + 19
RCL 13
1
RCL 16
—
*
STO IND 15
LBL 01
RCL 19
INT
STO 14
"MNT YR"
ARCL X
PROMPT
STO 17
RCL 12
RCL 14
5
—
Yx
*
ST + IND 15
RCL 11
RCL 14
Yx
RCL 16
*
RCL 17
*
RCL 00
RCL 14
5
—
Yx
*
ST- IND 15
ISG 19
GTO 01
RCL 14
"TRD YR"
ARCL X
PROMPT
RCL 12
RCL 14
Yx
1
RCL 16
—
*
*
ST- IND 15
RCL 12
RCL 15
Yx
1
+
RCL IND 15
*
RCL 11
1/X
1
—
*
RCL 11
1/X
RCL 15
2
*
Yx
*
LASTX
1
—
÷
STO IND 15
"AMORT"
ARCL X
AVIEW
STOP
GTO 02
END
```

```
LBL SELL
"OPT CYCLE"
PROMPT
STO 15
1
STO 18
RCL IND 15
RCL 11
1/X
RCL 15
2
*
CHS
Yx
1
X<>Y
—
*
RCL 11
1/X
1
—
÷
STO 19
"TRADE NOW"
PROMPT
1
RCL 16
—
*
—
XEQ 04
0
STO 17
LBL 03
RCL 18
"M T"
ARCL X
PROMPT
STO 14
X<>Y
STO 13
RCL 11
RCL 18
Yx
RCL 16
*
RCL 00
RCL 18
5
—
Yx
*
RCL 13
*
ST- 17
RCL 12
RCL 18
0.5
—
Yx
RCL 13
*
ST + 17
RCL 12
RCL 18
Yx
1
ST + 18
RCL 16
—
*
RCL 14
*
ST- 17
RCL 17
RCL 12
RCL 18
1
—
Yx
RCL 19
*
+
XEQ 04
GTO 83
RTN
LBL 04
"AMORTIZING"
AVIEW
RCL 11
1/X
1
—
*
RCL 11
1/X
2
RCL 15
*
RCL 18
+
1
—
Yx
*
LASTX
1
—
÷
CLA
"AMORT="
ARCL X
AVIEW
STOP
END
```

APPENDIX II

Two examples of the use of programmes RPLMT and SELL are given. The first is based on ASAE: data and the second is based on data provided by a farmer.

Example 1:

Assuming a tractor costs R15 000 and that its repair costs obey the function ARC = 15 000 × 0,012 $(X)^{2.033}$ – where ARC = accumulated repair costs and x is the accumulated hours of use divided by 1 000.

Year by year repair expenditure for a tractor completing 1 200 hours per year is given in the following table:

Year ..	1	2	3	4	5	6	7	8	9	10
Repair costs (R)	260	807	1 366	1 934	2 507	3 085	3 665	4 250	4 836	5 425

The resale value of the tractor would be determined by

$$RFV = 15\,000 \times 0{,}68(0{,}92)^n$$

here RFV is the remaining farm value (trade value) and n is the age in years.

The resale value from one to 10 years of age is as follows:

Age (years)	1	2	3	4	5	6	7	8	9	10
Trade value (R)	9 375	8 550	7 950	7 200	6 750	6 150	5 700	5 250	4 800	4 350

Appendix III is an example of the *pro forma* used to calculate the average replacement cycle for a vehicle obeying the above pattern for repair costs and resale value.

For the data chosen a 3-year replacement would be most economic, a situation created primarily by rapidly rising repair costs.

Example 2:

The data in this example are from a grower who requested advice. He runs a fleet of tractors which are all the same size and do similar work. The repair costs are the average for the fleet at various times and the resale data come from the Machinery Dealers Digest.

Because tyres are an expensive item the cost of replacement is included in the repair costs in years 3, 5 and 8. An engine rebuild is allowed for in years 4 and 8.

The dilemma the farmer faced was that when this tractor was three years old it had an unexpected transmission failure which cost R2 500 to repair. The scheduled maintenance would have been R1 800; therefore the total repair cost expected was R4 300 and the farmer wondered what he should do. The analysis of the data for the fleet indicated a 3 or 5 year replacement cycle. The grower chose a 5 year cycle. On this basis the three choices available were analysed, ie Sell now "as is" for R4 800 which gave a total mortgage cost of R2 577; repair and run for one year which gave an annual cost of R2 845; repair and keep going for two years which gave an annual cost of R2 357. The third option was cheapest and the correct choice to adopt for this vehicle. The results of this analysis are shown in Appendix IV.

APPENDIX III

CAPITAL REPLACEMENT DECISIONS

Programme RPLMT (HP41C)

Inflation rate (decimal) 0,15
Desired return on investment (decimal) 0,20
Capital value of new vehicle (R) R15 000
Marginal tax rate (decimal) .. .. 0,43 (Company tax)

Present value of maintenance and trade-in for an *average*, vehicle of ages:

Age (years)	1	2	3	4	5	6	7	8	9	10
Maintenance (R)	260	807	1 366	1 934	2 507	2 085	2 665	4 250	4 836	5425
Trade-in (R)	9 375	8 550	7 950	7 200	6 750	6 150	5 700	5 250	4 800	4350

Yearly repayment on a mortgage for a cycle length of:

Cycle length (years)	1	2	3	4	5	6	7	8	9	10
Yearly* repayment (R)	4 593	3 474	3 348	3 584	3 912	4 376				

Programme "SELL" (HP41C)

On the basis of the above optimum cycle (or any other cycle chosen) the individual vehicle is analysed as follows:

Chosen cycle length (years) : ————
"As is" trade value (R) : ————

	Maintenance (R)	Trade (R)	Mortgage repayment (R)*
Maintenance and reconditioning for a year from now and trade value after that year			
Maintenance for second year from now and trade value thereafter			

* Choose which ever option has the least mortgage repayment.

APPENDIX IV

CAPITAL REPLACEMENT DECISIONS

Inflation rate (decimal) 0,10
Desired return on investment (decimal) 0,15
Capital value of new vehicle (R) R12 000
Marginal tax rate (decimal) 0,43

Present value of maintenance and trade-in for an *average*, vehicle of ages:

Age (years)	1	2	3	4	5	6	7	8	9	10
Maintenance (R)	500	800	1 800	2 800	1 300	1 300	1 800	3 500		
Trade-in (R)	7 500	6 000	5 400	4 800	4 200	3 600	3 000	2 000		

Yearly repayment on a mortgage for a cycle length of:

Cycle length (years)	1	2	3	4	5	6	7	8	9	10
Repayment (R)	3 663	2 986	2 899	3 148	3 122*	3 146	3 263			

Programme "SELL" (HP41C)

On the basis of the above optimum cycle (or any other cycle chosen) the individual vehicle is analysed as follows:

Chosen cycle length (years) : 5
"As is" trade value (R) : 4 800 (3 years old)

	Maintenance (R)	Trade (R)	Mortgage repayment (R)
"As is"			2 577
Maintenance and reconditioning for the first year from now and trade value after that year	2 500 + 1 800 = 4 300	4 800	2 845
Maintenance for second year from now and trade value thereafter	1 300	4 200	2 357*

* Options chosen