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THE ROLE OF ECONOMIC EVALUATION IN THE DETERMINATION OF BUS REPLACEMENT POLICIES

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ABSTRACT: *This paper outlines a generalised model for the economic evaluation of bus replacements. It suggests that a warrant for replacement does not necessarily follow from a satisfactory outcome of an economic evaluation and that deferral of replacement may be justified. The model calculates net user benefits, maintenance cost savings and salvage values for projects involving the replacement of various aged buses. The summary criteria, Net Present Value and Benefit-Cost Ratios are determined for replacement and for deferral of replacement by one year. The difference in project net present values is used to determine the age beyond which continued operation of a bus is not warranted.*

Background Paper for Session 11,
also background for Session 4.

BUS REPLACEMENT POLICY

INTRODUCTION

In 1972, the Australian Bureau of Transport Economics (B.T.E.) outlined evaluation procedures for public transport vehicle replacements. This procedure recommended a "comparison of the cost of acquiring new rollingstock against the total value of the differences in the costs, for the operating authority and for the public, of using new vehicles instead of old".[1]

However, the problem of defining base and project cases was considered to be particularly difficult because "vehicles can be maintained in operation virtually forever if maintenance expenditure is extended to the replacement of every component of the vehicle". The B.T.E. argued that the appropriate base case was to assume that the vehicles under consideration would have to be replaced in 10 years time and that this base case was consistent with "safety and increasing maintenance expenditure over time". Table 1 shows that the B.T.E. has not consistently used this base case, as the replacement deferral period has varied from 5 to 10 years.

Further, in evaluations conducted by the B.T.E., the replacement cycles assumed to operate in the base case, after deferral, have varied from the expected life of the vehicle in the project case to this value plus a further period of deferral. Since 1974, the B.T.E. has assumed that the base case replacement cycle, after deferral, has been the same as the expected age of the project case bus and this approach is adopted in the model below. Replacement and maintenance costs in the base case are considered as benefits to the project being evaluated.

The project case was defined by the B.T.E. as being immediate replacement of the buses under consideration and then a cyclical replacement pattern based on the expected life of the replacement bus. This expected life was recognised to be specific to each project. The bus replacement cost used has not always been a reflection of the true resource cost of the project in that transfer payments have not been allowed for and the capital cost was sometimes calculated net of salvage value. In our model, we consider salvage value to be a benefit to the project when replacements are made in the project case and a negative benefit when replacements are made in the base case. The discount period used by the B.T.E. has also varied, from 50 years to 20 years and no sensitivity tests have been published by the B.T.E. on the effects of changes in this parameter.

The B.T.E. enumerated the quantifiable benefits as:

1. savings in vehicle maintenance costs
2. savings in vehicle operating costs
3. benefits to existing passengers

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1 Bureau of Transport Economics (1972), Appendix D17.

TABLE 1

BUREAU OF TRANSPORT ECONOMICS - BUS REPLACEMENT EVALUATIONS

		Base Case			Project Case			B/C Ratio	
Year of Evaluation	Deferral Period (Years)	Expected Life Of Bus (Years)	Patronage Forecasts (% change/year)	Salvage Value ($)	Expected Life Of Bus (Years)	Patronage Forecasts (% change/year)	Period (Years)	7%	10%
1972									
Project 22	10	30	-2	1,000 (a)	20	-2	50	1.4	1.3
Project 26	10	30	(b)	200 (a)	20	(b)	50 (c)	1.4	1.3
1973									
Project N9 (d)									
Project V10	10	32	-.4 (e)	3,500-0 (f)	15	-.4 (e)	50	2.3	1.1
Project S4	10	26	-.5 (e)	na	12	-.5 (e)	50	.9	.8
Project W4 (g)									
Project T1	5	15	-.5	500	15	-.5	50	.91	.86
1974									
Project V7 (h)									
Project Q2	10	20	na	1,700-0 (a) (i)	20	na	na	1.19	1.06
Project S3	5	16	0	na	16	0	na	1.15	.96
Project T1	5	15	na	na	15	na	20	1.07-1.25	.94-1.10 (j)
Project W5 (k)									
1975									
Project Q10 (l)									

Cont'd.

TABLE 1 (CONT'D)

(a) Deducted from capital costs.

(b) A decline of .55m passenger miles per decade from a 1970/71 base of 44.3m passenger miles.

(c) Calculated for each decade.

(d) Results assumed to be the same as for Project 22 in 1972.

(e) Expected percentage decline per decade/10.

(f) $3,500 for 15 year old buses $800 for 22 year old buses and zero for 32 year old buses.

(g) Results not calculated but assumed to be comparable with Project 26 in 1972.

(h) Not evaluated, but assumed to be comparable to the evaluation of Projects Q2 and S3 in 1975, and not significantly different from the results obtained for Project V10 in 1973.

(i) $1,700 for a 20 year old bus and zero for a 33 year old bus.

(j) Sensitivity tests were calculated on user benefits.

(k) Not evaluated but assumed to be similar to Project S3, 1975.

(l) Not evaluated but assumed to be similar to Project Q2, 1974.

(na) Not available.

Source: B.T.E., 1972, 1973, 1975, unpublished, op. cit.

4. benefits to new passengers, and
5. road traffic savings due to passenger conversion.

The unquantifiable benefits were taken to be:

1. improved conditions for operating staff
2. improved safety
3. reduced interference to other road traffic, and

these were not considered further. No general discussion of savings in vehicle maintenance or vehicle operating costs was undertaken in 1972 as these were considered to be specific to each project.

In 1973, the procedures and assumptions underlying the B.T.E. bus replacement model were virtually unchanged.(1) However, a generalised bus maintenance - age relationship was applied to all bus replacement projects. This relationship was considered to be of the form:

$$y = 6.83 + .155x$$

where y was the maintenance cost in cents per vehicle kilometre and x was the vehicle age in years. In 1974, the B.T.E. proposed an 'interim' maintenance cost function, based on actual maintenance processes(2) and this was used in their 1974 and 1975 evaluations.(3) This function is discussed further below.

Based on their work at the B.T.E., Carr and Mackay (1978) proposed a new method for the evaluation of rollingstock replacements. They objected to the definitions of the base and project cases previously used by the B.T.E. and cited four objections to defining the base case in terms of a continuation of an historical pattern of replacement.

Specifically, their objections were that:

1. An historical replacement pattern is not always evident.

2. Even if an historical replacement pattern exists, it is not necessarily a good indicator of a future optimal replacement pattern.

3. In terms of the States Grants (Urban Public Transport) Act 1974, the base case is identical to the project case, the only difference being a transfer of financing. They argued that exclusion of all such projects from consideration "is not how the Act has been interpreted in practice".

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1 Bureau of Transport Economics (1973).

2 Beck (1974).

3 Bureau of Transport Economics (1975a), (1975b).

4. Project cases have not been exhaustively defined in that only a few alternative replacement policies have been examined.

They assumed that, for the base case, there would be no replacement and the existing fleet would be operated and maintained indefinitely. For the project case, replacement of certain aged rollingstock would be made in a particular decision period and, thereafter, the rollingstock was assumed to be operated and maintained indefinitely with no further replacements being made.

Whilst accepting some of these objections to the B.T.E. model, the base and project cases defined by Carr and Mackay are considered to be unrealistic. The B.T.E. rejected these definitions in 1972 by arguing that "the costs of a maintenance programme of (the above) nature is most difficult to assess, as is also the effect of extremely old vehicles on patronage, safety and the time vehicles are out of service due to breakdown or for maintenance".[1] The B.T.E. definitions are therefore considered to be appropriate but the robustness of the evaluation results to changes in the various parameters, such as the deferral period and expected bus life, should be tested.

Carr and Mackay have ensured that alternatives to the base case, the so-called "do-nothing" case and the project case are now considered. This was done by calculating the increment in net present value by deferring replacement for one year. Where this incremental net present value is positive, immediate replacement can be deferred with a consequent gain in net community benefits. This method was used to determine the optimal age for replacing a bus and this was defined to be that age where net present value no longer improves by deferring replacement. However, the above logic results in an apparent inconsistency when an alternative evaluation measure, the benefit-cost ratio, is used in decision making. This matter is discussed at length below.

A GENERALISED MODEL FOR EVALUATING BUS REPLACEMENT

The review of the state-of-the-art indicated a need to improve evaluation methods for projects involving rollingstock replacement. For this reason, a generalised model was developed to determine the age beyond which deferral of replacement could not be economically justified. This model calculates net user benefits, maintenance cost savings and salvage values for projects involving the replacement of various aged buses.

The computer programme used to calculate the various summary criteria calls subroutines for these net user benefits, maintenance cost savings and salvage values. This allows insertion of alternative functional relationships for these variables, as well as sensitivity tests on the parameters used.

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1 Bureau of Transport Economics (1972), Appendix D17.

The equations used in the analysis are taken from the bus replacement models suggested by the B.T.E.[1] and by Beck (1974). The maintenance cost function used in both the base and project cases is of the form:

$$y(n) = An^B$$

where the cumulative cost of maintaining a bus, y(n) increases with distance travelled, n, and parameter A is associated with the cost structure of a particular operator and parameter B is dependent on the type of bus and the physical environment in which it operates. The particular equation used in the model is the interim function recommended by Beck (1974). That is,

$$y(n) = 2.5718 \times 10^{-2} n^{1.1086} \quad o \leq n \leq 420{,}00 km$$

This function has been adjusted to take account of changes in values since 1972.

The net user benefits accrue to existing, generated and converted patronage due to the value of improved comfort on the newer buses. The calculation of these benefits is based on procedures employed by the B.T.E.[2] The base case involves the immediate overhaul of the bus to be replaced by the project and its further maintenance for 10 years. A normal maintenance and replacement cycle of 15 years is then adopted. This is compared with a project case where the bus is immediately replaced and thereafter maintained and replaced as per the normal cycle. The sensitivity of the results to changes in the deferral period and the period of the replacement cycle is also calculated.

The model calculates the net present value and benefit cost ratio, from replacement, of buses varying in age from 7 to 30 years. In addition, the net present value and benefit cost ratio resulting from deferring replacement by one year is calculated. This gives the age beyond which deferral of replacement is not justified, but is not necessarily the only age for which bus replacement can be justified on economic grounds. The results of case studies presented in Tables 3 and 5 show that the summary criteria from deferring replacement are not sufficient to decide on an optimum replacement policy.

Decision Rules for Replacement

Two investment decisions have to be faced. These are:

1. Given a bus of age (r), is there any economic justification in replacing it with a new one? and

2. Given that a bus should be replaced, is there any merit in deferring replacement?

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1 Bureau of Transport Economics (1972), (1973), (1975a) and (1975b).

2 Bureau of Transport Economics (1972).

The first question can be resolved by examining the net present value and benefit-cost ratio as calculated by the model. To answer the second question, the model calculates these same cost-benefit summary formulations under the assumption that replacement is deferred one year. The decision rule for question 2 then becomes: "replacement should not be deferred if net present value begins to decline". However, it can be shown that benefit-cost ratios will always improve, or at least stay the same, so long as net present value is greater than, or equal, to zero. The benefit-cost rule would therefore suggest continued deferral is warranted. This apparent contradiction between the benefit-cost ratio and net present value results is resolved in the following analysis.

Let

Age of existing bus (in years) = r

Net discounted benefits (replacing immediately) = B

Net discounted benefits (deferring replacement 1 year) = B'

Net discounted costs (replacing immediately) = C = $\bar{C}$ (constant)

Net discounted costs (deferring replacement 1 year) $C' = C/(1+i)$

where, i = rate of discount

Net present value (replacing immediately) = N = B-C

Net present value (deferring replacement) = $N' = B' - C'$

Benefit-cost ratio (replacing immediately) = BCR = B/C

Benefit-cost ratio (deferring replacement) = $BCR' = B'/C'$

The decision rules are:

(1) For a bus of age (r), there is economic justification for immediate replacement provided that $N>0$, or $BCR>1$; and

(2) If condition (1) is met, replacement should not be deferred if $N'<N$.

Let p be the proportionate change in net benefits from deferring replacement by one year as against immediate replacement.

i.e. $B' = (1+p)B$ ...(1)

Capital costs remain the same in both cases, except that in the case of deferring replacement, costs are discounted by a further year.

i.e. $C' = \frac{1}{(1+i)} . \bar{C}$ ...(2)

$$(C'-C) = \left[\frac{1}{1+i}\right]\bar{C}-\bar{C}$$

$$(C'-C) = \bar{C}\left[\frac{i}{1+i}\right] \quad ...(3)$$

Equation 3 states that the benefit of deferring expenditure by one year is equal to $\left[\frac{i}{1+i}\right]$ times the capital costs.

Let ΔN be the change in net present value by deferring replacement one year rather than immediately replacing the bus.

$$\begin{aligned} \text{Then, } \Delta N &= N'-N \\ &= (B'-C') - (B-C) \\ &= (1+p)B - \left[\frac{1}{1+i}\right] C - B+C \end{aligned}$$

$$\Delta N = pB + \left[\frac{i}{1+i}\right] C \qquad \ldots (4)$$

Equation 4 states that the net present value will only decline when the benefits from deferring replacement decrease by an amount exceeding the present value of deferring costs by one year.

Assume that $\Delta N \leq o$

then $p \leq -\left(\frac{i}{(1+i)}\right) \frac{C}{B}$

$$\text{or} \quad p \leq -\left(\frac{i}{(1+i)}\right) \frac{1}{BCR} \qquad \ldots (5)$$

$$\text{Note also that } \frac{BCR'}{BCR} = \frac{B'/C'}{B/C} = \frac{(1+p)B.C}{B(1/(1+i)C}$$

$$\text{i.e. } \frac{BCR'}{BCR} = (1+p).(1+i) \qquad \ldots (6)$$

Note that so long as p is greater than $-\left(\frac{i}{(1+i)}\right)$, the benefit-cost ratio will always increase by deferring replacement.

Now, if $\Delta N \leq o$

$$\frac{BCR'}{BCR} \leq \left[1 - \left(\frac{i}{(1+i)}\right) \frac{1}{BCR}\right](1+i)$$

That is,

$$\frac{BCR'}{BCR} \leq \left[(1+i) - \frac{i}{BCR}\right]$$

or

$$\frac{BCR'}{BCR} \leq \left[1+i\left[1 - \frac{1}{BCR}\right]\right] \qquad \ldots (7)$$

Therefore, the benefit-cost ratio can only decline (assuming $\Delta N \leq o$) when:

$$1+i \left[1 - \frac{1}{BCR}\right] < 1 \qquad \ldots(8)$$

Assuming i is always positive, then

$$BCR \leq 1 \qquad \ldots(9)$$

or,

$$B \leq C \qquad \ldots(10)$$

From equation 6, it is apparent that the benefit-cost ratio will only decline when the proportionate fall in gross benefits is less than the proportionate reduction in costs due to discounting by one more year. From equation 4, it was deduced that the net present value can only decline when the absolute value of benefits from deferring replacement decreases by an amount exceeding the absolute value of the cost reduction due to discounting one more year. It was then demonstrated that, provided the net present value is initially greater than zero, the benefit-cost ratio will increase or stay the same while the net present value may decline. Because the net present value method compares changes in the absolute values of costs and benefits, rather than relative changes, it is to be preferred in interpreting the results of this model.

Case Studies

The model has been tested and evaluations of the possible replacement of buses in private operator fleets in the Brisbane region and by the Brisbane City Council are detailed below.

Private Bus Operators

There are presently 294 buses in private operator fleets in the Brisbane region. Table 2 shows the age distribution of private buses in Queensland as at June 30th, 1977 and, from this distribution, it has been estimated that approximately 58 private buses operating in the Brisbane region are at least 20 years of age.

The specific base and project cases used in the evaluation of private bus replacement in Brisbane are derived from the data in Table 2. The capital cost of new buses was estimated to be $60,000 per bus and the salvage value of buses of 15 years of age was estimated to be $2,000. The normal overhaul cost is taken to be $5,000 for a bus aged 8 years. In the base case, all buses are overhauled in the first year and this overhaul cost is assumed to be a function of the normal overhaul cost and the age of the particular base case bus being evaluated.

An analysis of patronage trends for private operators indicated an annual decline of 3 percent over the period 1968-1976, but this rate of decline increased to 10 percent per annum over the period 1974-76. It was therefore assumed that patronage would decline by 5 percent per annum until only captive users travelled on the buses.

Captive patronage is estimated to be 70 percent of 1977-78 patronage.

TABLE 2

AGE DISTRIBUTION OF PRIVATE BUSES IN QUEENSLAND

30TH JUNE, 1977

Age of Buses	Percent in Age Group
Up to 5 years	10.25
6 to 10 years	28.2
11 to 15 years	25.64
16 to 20 years	16.23
20 to 25 years	7.26
Over 25 years	12.39

Patronage calculations are based on an estimated average trip length of 10km.

Table 3 shows that the replacement of private buses greater than 17 years of age can be justified on economic grounds. The age beyond which replacement should not be deferred is 26 years. This is the age at which the net present value from replacement exceeds the net present value from deferring replacement for one year.

Brisbane City Council

The Brisbane City Council bus fleet, as at June 30th, 1978 consisted of 566 buses. The age distribution of these buses is shown in Table 4. While the mean age is 8.3 years, the modal class is 8-10 years. This age distribution is peculiar to Brisbane because of the conversion from trams to buses in 1968/9. A continuous replacement policy has not been adopted over the last 10 years and the mean age of the fleet is increasing over time.

The bus replacement model was again used to evaluate the age at which the replacement of Brisbane City Council buses could be warranted. The base and project cases used are the same as for the above private bus evaluations, with the input data modified to reflect the Brisbane City Council patronage and replacement costs. Specifically, the replacement cost is estimated to be $75,000 per bus.

TABLE 3

PRIVATE BUS OPERATORS - CASE 1

RBUS: BUS REPLACEMENT MODEL - M.T.A. 1978

BASE CASE BUSES AGED 15 TO 30 YEARS

DISCOUNT RATE = 10.00 PERCENT CAPITAL COST $60,000

EXISTING PATRONAGE - 1978 = 369 000 PASSENGER KM/YEAR/BUS

AGE OF REPLACED BUS		NET PRESENT VALUE FROM REPLACEMENT				INCREMENTAL NPV FROM DEFERRING REPLACEMENT BY 1 YEAR
In 1978-79 (Year)	In 1979-80 (Year)	In 1978-79 $	Benefit-Cost Ratio	In 1979-80 $	Benefit-Cost Ratio	$
15	16	-4823.94	0.92	-995.20	0.98	3828.74
16	17	-1065.10	0.98	2419.85	1.05	3484.95
17	18	2694.44	1.05	5835.53	1.11	3141.10
18	19	6454.68	1.11	9251.85	1.18	2797.17
19	20	10215.62	1.18	12668.81	1.24	2453.20
20	21	13977.26	1.24	16086.41	1.31	2109.15
21	22	17739.60	1.31	19504.64	1.38	1765.04
22	23	21502.64	1.38	22923.51	1.44	1420.87
23	24	25266.39	1.44	26343.02	1.51	1076.63
24	25	29030.84	1.51	29763.17	1.57	732.33
25	26	32795.98	1.57	33183.95	1.64	387.97
26	27	36561.83	1.64	36605.37	1.70	43.51
27	28	40328.38	1.70	40027.42	1.77	-300.96
28	29	44095.63	1.77	43450.12	1.84	-645.51
29	30	47863.58	1.84	46873.45	1.90	-990.13
30	31	51632.24	1.90	50297.42	1.97	-1334.82

TABLE 4

AGE DISTRIBUTION OF B.C.C. BUSES

JUNE 30TH, 1978

Age of Bus	Number in Age Group	Percentage in Age Group
0-2 years	97	17.1
2-4 years	8	1.4
4-6 years	0	0
6-8 years	0	0
8-10 years	321	56.7
10-12 years	60	10.6
12-14 years	80	14.1
	Total 566	

Patronage is estimated to be 1.9 million passenger kilometres per year per bus, assuming an average trip length of 10km, as at June 30th, 1977. This patronage is further assumed to decline by 5 percent per year to a captive patronage of 70 percent of the 1977 estimate. The results of the evaluations are shown in Table 5.

The evaluation results show that the replacement of Brisbane City Council buses over the age of 14 years is economically warranted. They further show that the deferred replacement of any bus over the age of 23 years cannot be justified. Given the skewed age distribution of the Brisbane City Council bus fleet, these results suggest a replacement policy to eliminate this skewness subject to the constraint that no bus over the age of 23 years continues in service.

CONCLUSIONS

In the past, economic evaluations of rollingstock replacements have employed inconsistent and questionable assumptions concerning base and project case definitions, evaluation period and cost and patronage inputs. Carr and Mackay (in 1972/73), attempted to develop a procedure which would avoid some of these problems and at the same time include a consideration of alternatives to the project case where buses were assumed to be replaced immediately. However, this work has had no impact in practice despite the importance of the topic. It is not surprising, then, that the trend has been to simply assume that there is an optimal age for replacing buses, often this is taken arbitrarily as 15 years or 20 years. Such assumptions have no empirical foundation and do not accord with what is known about the vehicle replacement policies of operators.

TABLE 5

BRISBANE CITY COUNCIL

RBUS: BUS REPLACEMENT MODEL - M.T.A. 1978

BASE CASE BUSES AGED 7 TO 30 YEARS

INCREMENTAL NET PRESENT VALUE FROM DELAYING REPLACEMENT OF DIFFERENT AGED BUSES BY ONE YEAR TO 1979-80

DISCOUNT RATE = 10.00 PERCENT   CAPITAL COST $75 000

EXISTING PATRONAGE - 1978 = 1 900 000 PASSENGER KM/YEAR/BUS

AGE OF REPLACED BUS		NET PRESENT VALUE FROM REPLACEMENT				INCREMENTAL NPV FROM DEFERRING REPLACEMENT BY 1 YEAR
In 1978-79 (Year)	In 1979-80 (Year)	In 1978-79 $	Benefit-Cost Ratio	In 1979-80 $	Benefit-Cost Ratio	$
7	8	-33293.07	0.53	-26804.04	0.59	6489.03
8	9	-29462.99	0.59	-22972.15	0.65	6490.83
9	10	-25247.92	0.65	-19136.99	0.71	6110.93
10	11	-21029.23	0.71	-14228.83	0.78	6800.41
11	12	-15627.27	0.78	-9317.39	0.86	6309.88
12	13	-10221.70	0.86	-4402.67	0.93	5819.03
13	14	-4812.52	0.93	515.34	1.01	5327.86
14	15	600.28	1.01	5436.63	1.08	4836.35
15	16	6016.68	1.08	10361.19	1.16	4344.51
16	17	11436.69	1.16	15289.05	1.24	3852.35
17	18	16860.31	1.24	20220.18	1.31	3359.87
18	19	22287.55	1.31	25154.59	1.39	2867.04
19	20	27718.39	1.39	30092.29	1.46	2373.90
20	21	33152.85	1.46	35033.27	1.54	1880.42
21	22	38590.91	1.54	39977.53	1.61	1386.62
22	23	44032.58	1.62	44925.07	1.69	892.49
23	24	49477.87	1.69	49875.89	1.77	398.03
24	25	54926.76	1.77	54830.00	1.84	-96.76
25	26	60379.26	1.84	59787.39	1.92	-591.88
26	27	65835.37	1.92	64748.06	2.00	-1087.32
27	28	71295.10	2.00	69712.00	2.07	-1583.10
28	29	76758.44	2.07	74679.24	2.15	-2079.19
29	30	82225.38	2.15	79649.76	2.23	-2575.62
30	31	87695.93	2.23	84623.55	2.30	-3072.38

An attempt has been made to clarify the matter; the prime aim has been to develop a model which produces results which conform with a priori reasoning. From all the evidence, bus operators tend to consider replacement when a major expense has to be incurred, such as with a major overhaul. The decision to replace immediately, or to maintain the existing bus in further use, seems to be related more to the customer appeal of a new bus and to obsolescence, rather than to the difference in the cost of maintaining and operating new buses as opposed to older buses. In practice, there seems to be a period during which replacement can be deferred depending upon availability of finance and the "appeal" of new buses.[1]

Our model indicates that there will be a point reached beyond which it is possible to demonstrate an economic case for replacement, although a stronger case can be made for deferring this action. There is another point beyond which continued operation of a bus cannot be economically justified. Between these points, an operator has flexibility and replacement policy can be influenced more by considerations of finance, customer appeal and obsolescence. These conclusions accord with known practice and the only argument could be with the inputs to the model which determine the two points.

Every attempt has been made to incorporate defensible assumptions concerning bus operator behaviour and has included the most up-to-date cost and benefit functions available.[2] Whilst we are of the opinion that these functions can be improved, the appeal of our model lies in its logic and in the conclusions it indicates. Tests have been conducted to gauge the sensitivity of model results to variations in the inputs and the evaluation results reported in this paper have been found to be robust.

The analysis demonstrates that an economic evaluation of bus replacement does not necessarily demonstrate a warrant simply because a favourable result is achieved and, in this sense, it is meaningless to talk of an optimal replacement age. The very factors which are most difficult to incorporate in the economic evaluation are the ones which will determine replacement policy, given the limits indicated in this analysis.

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1 See, for example, Nash (1974) and Haver (1977).

2 Since presentation of this paper, details of more sophisticated bus maintenance and operating cost functions have been published, see Beck (1978). Available data is inadequate and does not allow an application of the new functions.

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