



## **The economic life of urban buses: searching for truth**

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### **Abstract:**

Buses are a major item of investment in the urban public transport sector in Australia. Yet there has been surprisingly little robust analysis and little consensus on optimum bus replacement policies for buses in urban operations. The paper addresses this issue.

The paper first reviews the life cycle costing models used by various Australasian public bus operators, and appraises their structures, their critical assumptions and their findings. It finds a wide range of input assumptions and results.

It then reports on the development and application of a bus "life cycle costing" model in the context of Perth's urban route services. It covers the model structure; the development of the key input functions; the results of the model's application in determining optimum bus life; the implications of sub-optimum replacement policies; and the sensitivity of these findings to potential technology and efficiency improvements and other input parameters.

It concludes by discussing the implications of these findings for urban bus investment policies throughout Australia.

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## Introduction

Buses comprise one of the largest items of investment in the Australian urban public transport sector. Total investment in new buses in Australia is in the order of \$300 million per year, about half of which relates to urban route services. Correct investment decisions are vital to the viability of bus operators in financially-constrained and competitive situations.

Despite this, there has been surprisingly limited robust analysis and little consensus on optimum bus replacement policies for buses in urban operations. This paper addresses this issue, through the development of appropriate 'life cycle costing' models and their application in determining bus replacement policies for Perth's bus fleet.

The first main section of the paper appraises the requirements and formulation for an appropriate bus 'life cycle costing' (or optimum replacement) model, and discusses key issues and data considerations for such a model.

In the light of this appraisal, the next section reviews the 'life cycle costing' models used by various Australian public bus operators over the last 10 years - in an attempt to shed light both on appropriate modelling methods and on the results of applying these methods. It reviews these models in terms of their structures, their critical input assumptions and their findings.

The following section reports on the development and application of a bus 'life cycle costing' model in the context of Perth's bus fleet. It covers the model formulation; the development of the key input functions; the results of its application in determining optimum bus life; the implications of sub-optimum replacement policies; and the sensitivity of these findings to potential technology and efficiency improvements.

The paper then reports on the further application and extension of the model to assess the costs of ownership and maintenance of the Perth fleet up to year 2010, and how these costs are affected by the replacement policy adopted.

The paper concludes by summarising the implications of the work for urban bus investment policies throughout Australia.

The work reported here was undertaken by Booz Allen & Hamilton for the Department of Transport, Western Australia, as part of its appraisal of the merits of out-sourcing the ownership, management and maintenance of the Perth bus fleet. The authors would like to thank the Department (in particular Mr Jim Fitzgerald) for its support in undertaking the project and for its permission to publish the findings. We also acknowledge the assistance of a number of major public bus operators throughout Australia in terms of providing access to their own 'life cycle costing' models.

## Model requirements and issues

The question to be addressed

To determine the economic (optimum) life of buses in a fleet, the question to be addressed is essentially:

*What vehicle replacement (life) policy will minimise the total net costs of providing the defined level of bus services over the longer term?*

The 'life cycle costing' (LCC) model required to address this question should model how the total costs for a fleet to provide a given amount of service (and hence the average annualised net costs per kilometre) vary with the age of the buses at replacement, and should derive the minimum for this function of cost/kilometre against replacement age.

In this context, total net costs (subject to discounting as appropriate) would include:

- Capital costs
- Recurrent (operating and maintenance) costs
- Any changes in net revenue resulting from changes in patronage.

The optimum vehicle replacement policy may well depend on technological developments affecting buses (e.g. improved fuel consumption) or on changes in standards being imposed (e.g. requirements for low floor 'accessible' buses). Such developments will tend to shorten the lives of existing vehicles relative to their optimum lives in a 'steady state' situation. Clearly such developments need to be taken into account in any comprehensive model, as described later in the paper.

For some purposes, a useful simplifying assumption is to ignore such developments and assume a 'steady state' situation, i.e. at the end of their lives existing buses will be replaced by essentially similar buses, with similar capital and recurrent cost functions (aside from the effects of inflation). With this simplifying assumption, we can treat all buses as identical, and the question above can be replaced with a simpler question relating to a single 'typical' bus:

*At what age should a typical bus be replaced to minimise its average annualised net costs per kilometre?*

### Approaches to model formulation

Generally LCC models are formulated as:

$$\text{Minimise } t_n = \frac{1}{(k \cdot n)} * \sum_{i=1}^n \frac{(C_i + O_i - R_i)}{(1+r)^i}$$

where:

- $t_n$  = discounted average net cost/kilometre over bus life;
- $C_i$  = capital costs,  $O_i$  = recurrent costs,  $R_i$  = revenue changes (year  $i$ );

- $r$  = discount rate;
- $C_i, O_i, R_i$  may be functions of  $k_i$ , the distance operated in year  $i$ ;
- $k_i$  are such that:
  - $\sum k_i = nk$ , where  $k$  is the average annual distance per bus (to match the overall service requirements)
  - $k_i$  are optimised to ensure that the total cost function ( $t_n$ ) is minimised;
  - $n$  = bus life (years).

Essentially, the model is required to find the minimum value of  $t_n$  over two variables, i.e. bus life (all possible values of  $i$ ) and profile of annual distance by bus age (combinations of  $k_i$ ).

Two basic types of models can be used:

- 'Optimising' models, which directly determine the values of  $n$  and  $k_i$  which minimise  $t_n$ .
- 'Deterministic' models, which calculate  $t_n$  for given values of  $n$  and  $k_i$ . By running the model multiple times, the minimum  $t_n$  value may be determined.

In the 'steady state' situation (described above), it can be readily shown that the model formulation can be simplified so that the result is independent of the discount rate

However, in other cases the discount rate adopted will affect the results. For example, in the case of technology improvements which reduce operating/maintenance costs of future buses, the optimum life of existing buses would be shortened (relative to the 'steady state' situation); but the extent of such shortening would diminish over time (as the recurrent costs would account for a lesser proportion of total costs). Higher discount rates would reduce the effects of any future cost savings on shortening optimum bus life

#### Issues and data considerations

*Bus deployment and operations aspects:* One essential input to any LCC model is the profile of deployment of the 'typical' bus over its life. Buses rarely (if ever) have a consistent usage pattern over their life. A typical usage profile might have five phases over the life of an urban service bus (from new to old):

- All weekday and weekends
- Weekday peak and interpeak only
- Weekday peak (route and school) only
- Peak school only
- Reserve stock only (cover breakdowns etc.).

Annual distances operated over these five phases might range from approaching 100,000 kms pa to less than 10,000 kms pa. (Because of this pattern, average costs/kilometre may increase rapidly in the later years, solely because the fixed costs are spread over fewer kilometres.)

The LCC model needs to incorporate an optimum deployment profile corresponding to each assumed bus life. As noted above, the deployment profile needs to be such as to

result in a consistent average annual kilometres/bus over the full bus life, corresponding to the overall requirements for the operation (eg an average 50,000 kms pa per bus). In theory, it might be desirable to test a range of deployment profiles and hence determine that profile that minimises costs (for any assumed bus life). However, in practice this is probably not necessary, as there is a very limited practical range of deployment profiles which would cover the service profile and satisfy the requirements for the overall average kilometres per bus.

The LCC model also needs to consider any trade-off between bus life and spare bus requirements. This aspect appears to be neglected in most models, but may be significant. As an indication, industry practice would tend to suggest a spare ratio of perhaps 7-8% for relatively 'young' fleets (say maximum age 12 years), increasing to perhaps around 12% for relatively 'old' fleets (say maximum age 25 years). This would indicate that the effect should certainly be incorporated in any LCC model

*Bus capital aspects - issues and data:* LCC model inputs relating to bus capital costs will be:

- Bus purchase price
- Bus sale price (at time of replacement)
- Spare bus ratio (as discussed above).

Assuming buses are purchased new in every case, the bus purchase price will be independent of the bus life, in a basic model. A more complex model might examine the relative costs of different types of buses (e.g. heavy v light duty) over a range of bus life assumptions

The bus sale price should reflect its open market value. If the market were homogeneous, then the sale value would be such as to make the owner indifferent between sale and non-sale: in this case the optimum life would be indeterminate. But in practice the market is not homogeneous, and the optimum sale point is when the market value exceeds the value to the original owner.

The economic depreciation of buses, and thus their second-hand market values, varies with the bus age and, to a lesser extent, the cumulative distance operated. A typical economic depreciation function would be 12.0%pa, on a diminishing value basis (real terms).

Market values are also likely to depend on the extent of any major refurbishment/overhaul work undertaken. One of the major issues in determining optimum bus life is whether prolonging the life by major rebuilding (after, say, 12-15 years) is economically warranted. Important factors in such an analysis are the rebuilding costs and the effects of the rebuild on subsequent operating/maintenance costs and resale value. For each assumed bus life, the analysis needs to determine the optimum assumptions on bus rebuilding (extent and timing), and then to incorporate a consistent set of assumptions on rebuilding costs, operating/maintenance costs and sale values in determining the whole of life costs.

*Bus operations and maintenance aspects - issues and data:* The recurrent expenditures for a bus company may be classified into three groups for modelling purposes:

- (A): Costs which are independent of bus age or life-time distance operated. This group includes all operations costs (drivers, scheduling etc.), all bus 'fixed' costs and a substantial proportion of bus repairs, servicing, etc. costs. These costs are not considered further, except insofar as they may be affected by the spare bus ratio.
- (B): Costs which are wholly or partially dependent on life-time distance operated. These may include mechanical repairs and major mechanical overhauls. The shape of the cost functions needs to be considered in developing the model inputs.
- (C): Costs which are wholly or partially dependent on bus age. These may include body repairs and major refurbishment. Again the shape of the cost functions needs to be considered in developing the model inputs.

*Patronage and revenue aspects - issues and data:* The main issue for consideration here is the extent to which having a newer fleet (on average) will be more attractive to passengers, and hence generate additional revenue. This is another aspect on which most existing models appear to be weak.

The following comments should be made on this aspect:

- There is only very limited evidence (in Australia and internationally) on the extent to which newer buses generate additional patronage, when all other factors are equal. The patronage generation of a new bus seems likely to be 'a few percent' greater than say a 15 year old bus. Thus the effect may be small but significant in the model analyses.
- Appropriate bus body refurbishment (internal and external) may give an older bus many of the passenger-generating features of a newer bus; and therefore new buses may not be necessary to achieve much of the potential revenue benefits.
- To the extent that part of any patronage generation is likely to occur on peak-period peak-direction buses which are already effectively full, additional buses may be needed. This needs to be allowed for in any assessment of net revenue impacts.

We consider the most appropriate approach is to assume zero net revenue impacts for the basic model application, but to assess the impacts of potential revenue changes through sensitivity testing.

## **Appraisal of Australasian practice**

### **Scope of appraisal**

We reviewed the economic bus life models developed by the major public sector operators in five Australian cities and one New Zealand city: Perth, Canberra, Brisbane, Adelaide, Darwin and Auckland.

These models are generally similar in overall structure and scope and are of the 'deterministic' type: they assess the discounted 'whole-of-life' costs for different bus lives, from which the optimum life may be established. Mostly, they are essentially



single bus models, used to find the optimum life for a typical bus of a given type. Some of them have been applied to overall fleets, others to a single typical bus (or bus type).

In general, they address the question of what is the optimum age to replace a bus by a bus of a similar type and cost structure. The Adelaide model had been developed to assess the optimum time to replace an old bus type by a newer type (with lower unit costs).

#### Model features and input assumptions

The following provides a summary of the key features and input assumptions of the models in each of the six cities (the relevant references are given at the end of the paper).

#### Evaluation parameters:

- Discount rate: rates used in different models were between 3% and 10% (real), with sensitivity testing in some cases.
- Evaluation period: based on 'bus life' in some cases, between 17 years and 25 years in other cases.

#### Operations aspects:

- Bus distance v age function: some models divided annual distance/bus into about 6 groups, according to bus age; others assumed constant annual distance/bus over the whole fleet (a significant weakness).
- Spare bus ratio: no apparent allowance in any models for this to vary with age policy.

#### Bus capital aspects:

- Bus sale prices: assumptions unclear in some cases; in others value after 15 years ranges from 5% to 25% of new bus price.

#### Recurrent cost aspects:

- Running (fuel, oil, tyres) costs: generally assumed independent of bus life, although one city assumed increase at 3%pa.
- R&M costs: cost factors generally developed from analysis of maintenance cost records and/or 'engineering judgement'. Some models dealt with refurbishment/overhaul costs separately, as one-off costs at particular ages or cumulative kms; others combined these with routine maintenance costs, in cost functions varying gradually by age and/or cumulative kms.

#### Revenue aspects:

- No models allowed for revenue varying with age policy.

While the models differ from each other in a great number of respects, perhaps the most critical area is in the recurrent cost aspects, and specifically in the variation of bus repairs/maintenance costs as buses age. This tends to be the most uncertain modelling area, in which there are great variations in input assumptions and in which overall model results are sensitive to these assumptions.

## Summary of model results

Table 1 provides an overview of the model results from the six cities, in terms of optimum replacement age and how whole-of-life costs vary with variations from this age. Notable features are:

- Optimum life varies from 5 years (Brisbane) to 20 years (Perth). For the three cities which (arguably) have the most sophisticated models, optimum life is 5 years for Brisbane, 7-8 years for Canberra and 20 years for Perth.
- The cost NPV v age functions are relatively flat either side of the optimum age. The table shows that the cost NPV is within 5% of the minimum level over considerable age ranges (eg 3-9 years for Brisbane, 12-25 years for Perth).

In contrast to this wide range of 'optimum' life values, in practice all the six cities adopted replacement age policies of between 15 years and 20 years.

**Table 1: Overview of Australasian model findings**

City	Optimum Age from Model (years)	Age Range within 5% of Minimum Cost NPV	Key Comments on Model Quality and Findings
Perth	20	12-25	<ul style="list-style-type: none"> <li>• Considerable doubt re factors used to adjust recurrent costs for variations in bus age policy</li> <li>• Sensitivity tests on recurrent costs gave optimum age in range 16-36 years.</li> </ul>
Canberra	7-8	2-10	Full model details not available.
Brisbane	5	3-9	<ul style="list-style-type: none"> <li>• Reasonableness of recurrent cost functions by distance operated open to question</li> <li>• Found costs for 20 year age policy c.20% higher than optimum</li> <li>• Recommended best compromise replacement age as 9-10 years (just before onset of major overhauls)</li> </ul>
Adelaide	17	N/a	• Application specific to replacement of Volvo B59 buses: does not address bus replacement on a like-for-like basis.
Darwin	10 (rigid) 9 (artic)	6-14 (rigid) 4-14 (artic)	<ul style="list-style-type: none"> <li>• Ignored variation in bus kms with bus age</li> <li>• Assumed very high rate of increase in both R&amp;M costs and fuel costs with age.</li> </ul>
Auckland	15		• Ignored variation in bus kms with bus age, but otherwise generally appears sound.

## Conclusions re Australasian models

The model results indicate that optimum bus age varies from 5 years to 20 years. The Perth model indicates an optimum bus age of 20 years, which is generally consistent with the replacement policy which has been adopted in Perth for some years. However, the discounted total cost curve is relatively flat, for Perth as elsewhere: any replacement



policy at between 12 and 25 years would increase the total discounted cost by no more than 5% above the minimum level

The two other apparently most sophisticated models (Canberra, Brisbane) indicate optimum replacement age in the range 5 - 8 years. More detailed appraisal of the individual models would be necessary to fully analyse the reasons for the different results from the different models (full details of the Canberra model in particular were not available).

Prima facie, there are few factors which differ significantly between the six operators reviewed which would legitimately result in major differences in the optimum bus age. Our assessment is that the single most critical area of difference is in the input assumptions relating to how recurrent costs vary with bus age and cumulative bus kilometres. It is not clear that the differences in assumptions reflect real differences.

Based on this appraisal of the Australian models, no firm conclusions could be drawn regarding the optimum economic bus age: it could only be said with some confidence that the optimum age is between 5 and 25 years!

Little wonder that in practice, the bus age policies of Australian public operators hitherto appear to have been influenced more by the availability of funds year-by-year rather than by any results from economic models.

### Perth model development and application

#### Model formulation

We developed a deterministic model to address the issue of the optimum bus life policy for Perth. Such a model calculates the whole-of-life costs for a given set of input assumptions, including bus age at replacement. Multiple runs of the model were performed, varying the replacement age, and the optimum age policy was then deduced from inspection of the results.

A deterministic modelling approach has two advantages over an optimisation approach:

- The model formulation is simpler in mathematical/computing terms.
- It provides information on the variations of costs over a whole range of life options

Two sub-models were developed: a basic, 'steady state' model, assuming future buses have the same cost functions as existing buses; and a 'technology improvement' model, allowing for trends in unit recurrent costs for future buses.

The 'steady state' model effectively calculates the capital and recurrent costs over each year of its nominated life for a single (peak) bus; sums these costs over the life; then divides by the total kilometres operated to derive an average cost/kilometre. It covers one peak bus (i.e. a physical bus plus an appropriate spare bus allowance, which can vary with bus life) and the total kilometres associated with this peak bus. It should be commented that:

- Assuming a steady state situation (with buses purchased in future having the same cost function over their life as buses currently in the fleet), then summing the costs for one (peak) bus over its life is equivalent to summing the costs for a single year for a fleet with ages distributed evenly over the total life-span. The costs for such a fleet will be the same every year.
- Given this, there is no necessity to discount costs in the model: the optimum life is independent of the discount rate.

#### Model features and inputs

The principal model inputs were a set of operational assumptions and a set of cost assumptions.

The bus **operations/deployment** module was formulated such that the annual distance run by each bus varies over its life in a way consistent with actual bus deployment policy (i.e. newest buses used most intensively) and the observed average annual kilometres per bus. The distance operated per bus each year varies with the bus life policy assumed.

Table 2 sets out the service profile assumed and the associated bus kilometres run. This is based on data from MetroBus (Perth) supplemented by data from other Australian operators. It is used to divide all buses into five groups, according to annual kilometres operated.

**Table 2: Assumed Bus Service Profile And Annual Distance Operated**

Period	Kms pa/Bus Deployed	% of Peak Fleet Deployed	Average Kms pa/Peak Bus
Peak	30,000	100	30,000
Interpeak	35,000	50	17,500
Evening	35,000	20	7,000
Saturday	15,000	35	5,250
Sunday	15,000	15	2,250
Total	130,000		62,000

The **cost assumptions** input to the model (for a standard size bus) are summarised in Table 3. Particular features worthy of comment include:

- **Spare bus ratio.** Assessed to vary with bus life policy, based on operator practice and experience.
- **Bus sale price.** Price expressed as a function of bus age and cumulative distance operated, based on evidence from sale prices in Perth and elsewhere plus informed judgement.
- **Maintenance and overhaul costs.** Comprise an age-related component (c 20%) and a distance-related component (c 80%); with the distance-related component increasing for higher cumulative kilometres. (Initial trials of the model used separate refurbishment/overhaul costs, on a 'lumpy' basis (eg in year 12, or after 800,000 kms). However, it was difficult to ascertain how these cost functions would vary with bus life, and how they would affect sale values. It was consequently decided to

pursue the approach of incorporating refurbishment/overhaul costs within the overall maintenance cost function.)

Table 3 : Cost Input Assumptions (All Figures In \$1997)

Item	Cost Function
Bus Purchase Price	\$290,000 (standard size bus)
Bus Sale Price	Depreciation from purchase price taken as a function of age and kms operated, on a % pa diminishing value formulation: <ul style="list-style-type: none"> <li>• Age depreciation = 10.5% pa</li> <li>• Distance depreciation = 3.3% per 100,000 kms</li> </ul> (NB: Equivalent to c.12.5% pa DV for a bus with average usage).
Spare Bus Ratio	Spares ratio expressed as a function of bus life: <ul style="list-style-type: none"> <li>• 7.5% for life up to 10 years</li> <li>• Increase at 0.25% per year of life 10 - 20 years (e.g. 10.0% for 20 year life policy)</li> <li>• Increase at 0.5% pa per year of life over 20 years (e.g. 15.0% for 30 year life policy)</li> </ul>
Maintenance and Overhaul Costs	R&M costs are expressed as a function of age (c.20%) and kms operated (c.80%): <ul style="list-style-type: none"> <li>• Age-related (body, servicing etc.): \$1500 pa/bus for new bus increasing by \$150 pa/bus each year</li> <li>• Distance-related (mechanical etc.): 8.5¢/km for a new bus; increasing continuously at rate of 1.65¢/km every 100,000 kms up to 700,000 total kms; then at 3.3¢/km every 100,000 km up to 1 million total kms; increasing thereafter at 6.6¢/km every 100,000 kms.</li> </ul>
Bus-related Costs	Variable overhead operating costs affected by the changes in the size of the bus fleet, estimated at \$5,000 pa/bus.

The model did **not** include:

- Cost items which would be unaffected (in fulfilling a given transport task) by the bus life policy - including all driver costs, tyres, fuel, fixed overheads.
- Any potential variations in revenue associated with different bus life policies (e.g. because of newer buses being more attractive to passengers).

The model was developed using EXCEL 5 spreadsheets, with auxiliary programming in Visual Basic. Amendments, sensitivity tests etc. could therefore be carried out readily.

#### 'Steady state' model results

The 'steady state' model results in terms of average cost/bus kilometre, for bus life from 1 to 40 years, are shown in Figure 1. Key findings from these results include:

- The optimum bus life appears to be in the range 18 - 20 years. However, the cost is within 1¢/km (about 2% of the cost items included) of the minimum value over a range of 16-22 years.
- For lives of less than 16 years, the average costs increase moderately slowly down to age 11 years: the 11 year cost is under 6¢/km (about 10% of included costs) higher than the minimum. For shorter lives, the costs increase considerably faster.

- For lives of more than 22 years, the average costs increase slowly: at 28 years, the average cost is only about 6¢/km (10% of included costs) higher than the minimum figure.
- The main components influencing these cost trends are the capital, which decreases continuously with life; and the bus R&M, which increases continuously. The bus-related costs (ie the effects of the change in spare bus ratio) make only a very small contribution to the total cost changes.

#### The technology improvement model

This further development of the 'steady state' model allows assessment of the effects of technology improvements on the unit costs of future buses, and of the resulting implications for overall bus life. The 'technology improvement' model assumes that the recurrent cost functions over the bus life will be X% lower for a bus purchased in year (n+1) than for a bus purchased in year n.

The tests undertaken assume that unit recurrent costs decrease at 1%pa, 2%pa and 5%pa for both fuel costs and R&M costs. Review of evidence and discussions indicate the following as the most plausible assumptions:

- R&M costs: most likely rate of decrease 1% pa; probable range 0% pa to 2% pa
- Fuel costs: most likely rate of decrease 1% pa; probable range 0% pa to 2% pa. The evidence on trends in fuel consumption for newer buses is somewhat conflicting: while the weight of evidence indicates some decrease in consumption rates, there is some contrary evidence, suggesting that underlying efficiency improvements are being offset by higher emission standards, more extensive/powerful air-conditioning etc.

Because the assumptions of the steady state model that every vehicle is the same do not hold, the discount rate and the start year for the analysis are significant. It is necessary to calculate a discounted present value.

The 'technology improvement' model calculated the PV of the cost stream over a 120 year period (with a discount rate of 7% real) for different bus lives (120 years was chosen as the lowest common multiple of the ages being tested).

The results are summarised in Table 4. They indicate that:

- The optimum bus life decreases as the rate of technology improvement increases (as expected). Optimum life reduces by about 1 year for each 1% pa reduction in R&M/fuel costs.
- For a unit cost reduction of 1 - 2%pa, the optimum life falls from 18 - 19 years (zero change) to some 17 years.
- In all cases, the cost curve is relatively flat either side of the optimum.

Table 4: Effects Of 'Technology Improvements' On Optimum Bus Life

Scenario (R&M/Fuel Costs)	Optimum Life - Years	Years Within 1% of Min. Cost
No change	18-19	16-22
- 1%pa	18	15-20
- 2%pa	17	13-19
- 5%pa	13-16	? -18

#### Assessment of Perth fleet 'baseline' costs

##### The task

The WA Department of Transport proposed to out-source the ownership, expansion and management of the Perth bus fleet for a 12 year period (1998-2010). As an input to the assessment of private sector bids, BAH was asked to make a 'baseline' estimate of costs for the fleet over this period if it were to be retained in Government ownership. These estimates were to be used as a 'baseline' against which private sector bids could be compared; and also to identify the cost differences over the 12 year period from different bus replacement policies.

Our 'baseline' assessment covers the following cost items:

- Capital costs associated with taking over the existing fleet
- Capital costs for new vehicles, to allow for fleet replacement and projected fleet expansion over the period (see below)
- Residual (market-based) values of the fleet at the end of the 12 year period.
- Recurrent costs for those functions that would otherwise be contracted out to the private sector fleet manager.

Two sets of recurrent cost assumptions were assessed:

- Contract cost assessment - costs for those functions that would otherwise be contracted out to the private sector fleet manager. These were bus R&M costs, some bus-related costs (registration, third party, bus insurance) and fleet administration/management costs.
- 'Resource' cost assessment - all the above costs plus other cost items that would vary according to the bus life/replacement policy adopted. The additional costs involved here are the remaining variable component of bus-related costs (eg bus cleaning, variable bus-related overheads) and the fuel costs.

##### Key inputs

The key inputs to the assessment were as follows:

- **Peak bus requirement.** This was taken to increase from the current level of 832 rigid bus equivalents (RBE) to reach 976 RBEs in year 12. This allows for expected patronage growth.

- **Spare bus ratio.** The current ratio was 10.9%. By the end of the contract period, it was assumed this would reach a level consistent with the then maximum bus age, calculated from the model (refer Table 3).
- **New bus purchases.** A range of purchase rates were examined, from 60 buses per year (sufficient to broadly retain the current maximum and average fleet ages) up to 120 buses per year (sufficient to reduce the maximum bus age to 8 years by the end of the contract period). 80 buses per year were required to achieve the optimum age of 18 years.
- **Bus purchase and sale prices.** The model was used to assess the initial costs of the existing fleet, purchase/sale costs during the contract period, and the final sale value of the fleet at the end of the period (as Table 3).
- **Recurrent costs.** Two sets of assumptions were used - one for the resource cost assessment, one for the contract cost assessment.
- **Technology improvements.** Assumed to result in R&M costs and fuel costs for newer buses relative to older buses being 1% lower for each one year difference in date of manufacture.
- **Fleet management costs.** These were estimated for public and private ownership (they are not affected by the rate of bus purchases).
- **Discount rate.** All costs were discounted at 7% pa (real) to the start of the contract period (assumed July 1998).

## Results

For the 'resource cost' assessment, Figure 2 summarises how the discounted capital and recurrent (operating) costs for the 12 year period vary as the annual rate of bus purchase increases. (The 'contract cost' assessment results are not presented here, but were broadly similar to the 'resource cost' assessment.)

Under the minimum case examined of replacing 60 buses per year, by the end of the 12 year period the age of buses at replacement would be 21.0 years (similar to now), with an average fleet age of 10.4 years. Total capital expenditure on new buses would be \$209 million over the period. Under the maximum rate of replacing 120 buses per year, by the end of the period the age of buses at replacement would be 8.0 years, with an average fleet age of 4.4 years. Capital expenditure involved over the period would be \$418 million.

It is evident from Figure 2 that as the number of buses purchased increases, the discounted incremental (net) capital costs over the period are broadly twice the savings in recurrent costs. This result is not contradictory to the earlier conclusion that the optimum bus life is about 18-20 years. It reflects that the 12 year period does not cover the full life of the buses, and that the recurrent cost savings from the additional buses purchased would continue beyond the period.

## Conclusions

This paper has summarised a project to develop a 'life cycle costing' model for the Perth bus fleet, and to apply this to determine the optimum bus life and the future capital and recurrent costs of the fleet.

Our appraisal of 'life cycle costing' models used by major Australasian public bus operators indicates some significant weaknesses, primarily in terms of their input assumptions. These models indicate optimum bus life ranging between 5 years and 20 years. While there may be some differences in situations between the cities appraised, the major part of the differences in model results is considered to relate to unjustified differences in input assumptions. The most critical input function is that as to how bus repairs/maintenance (including refurbishment/overhaul) costs vary with bus age and distance operated; the second most critical function is how annual kilometres per bus varies with bus age. The different models have a wide range of assumptions on both these aspects, and hence a wide range of results.

In the light of this appraisal, we have developed a deterministic model to estimate life cycle costs for the Perth fleet, according to the bus replacement policy adopted. The main findings are:

- The optimum life in the 'steady state' situation is some 18-19 years.
- This optimum life reduces by about one year for each 1% pa improvement in maintenance and fuel costs for newer buses. In practice, the reduction in optimum life from this technology improvement effect seems unlikely to be more than 1-2 years.
- In either case, selection of a replacement life within about 3 years (either side) of the optimum will increase costs by only some 1¢/km (ie around 0.5% of total costs).

The analyses have not allowed for any additional patronage effects of newer buses, nor other intangible factors. If some allowance is made for these, our conclusion would be that the optimum life is most likely to be in the range 14-18 years in the Perth context. We consider it is unlikely to be substantially different for public bus operators in other Australian cities. This finding is not inconsistent with normal replacement practices (typically about 15 years); but differs from that of the Brisbane and Canberra model assessments in particular.



Figure 1 : Average Cost per Kilometre v Bus Life

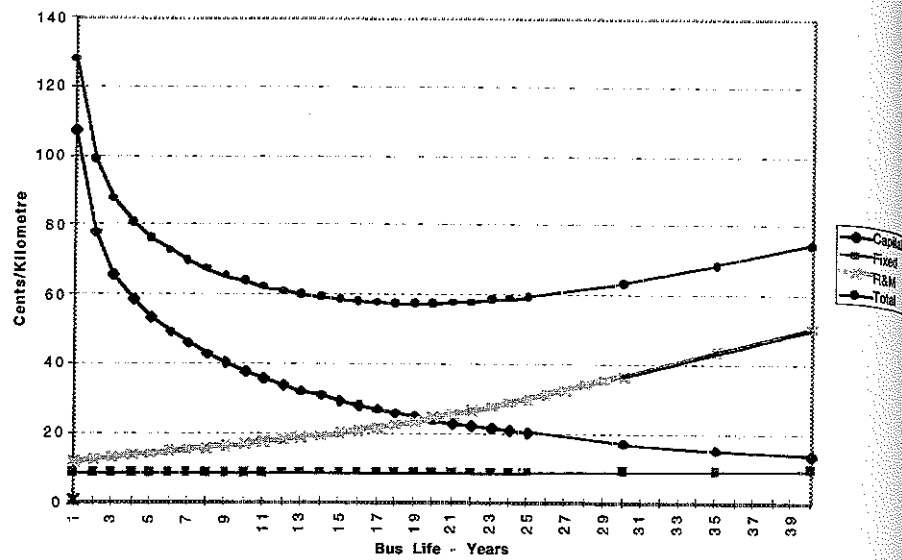
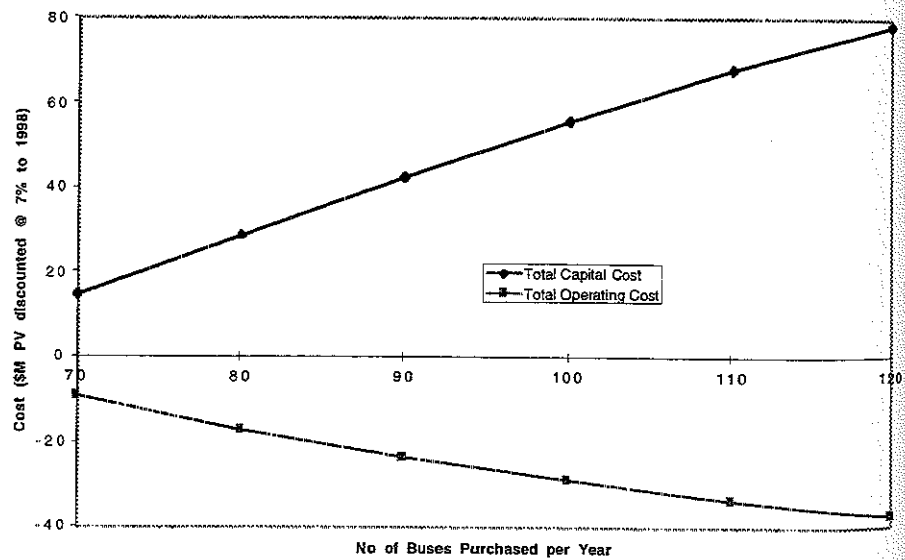


FIGURE 2: BUS PURCHASE OPTIONS: COST VARIANCE FROM 60 BUS OPTION



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