Life Cycle Cost of Australian Route **Buses**

Dr Robbie Napper - Department of Design, MADA
Dr Paul Thambar - Department of Accounting, Monash Business School A/Prof Ralph Kober -
Department of Accounting, Monash Business School Sarah Roberts – Department of Design and
Public Transport Research Group

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1. Abstract

This research set out to investigate life cycle cost (LCC) differences between Volgren bodied buses and others in the Australian market. A model was constructed based on AS4536 *"Life Cycle Costing – An Application Guide"* then data collected to represent cost generating activities of bus operations which may differ by bus body. These activities fall under four categories: acquisition, use and maintenance, renewal and adaptation, and disposal.

Information was obtained from operators by means of data reports and interviews. The data reports answered specific questions on cost generating activities, and also validated the scope of the study by reporting on the particulars of buses used in the study. Interviews via telephone and in person allowed the research to understand and better represent some of the nuances around servicing, accident repair, refit and disposal which are not easily represented in the model.

The data collected offer one major comparative case backed up through nine different buses overall in the study. These nine buses are from three operators and four different depots.
The participating operators are not identified to protect the confidentiality of their data input.

The research finds that Volgren buses offer life cycle cost savings to bus operators. The two primary savings are in fuel use and corrosion resistance. Another substantial saving is in the requirement to, and the intensity of, mid-life refits. The comparative case in this research shows a saving of $0.057 per km, or 7.3%, between Volgren and the compared bus. Several other minor cost generating areas were also discovered to have minor impact and the research identifies areas for future work to add detail to this research.

2. Aim and scope

The research aims to identify differences from bus bodies in life cycle cost for route buses in the Australian market. The primary method used is a life cycle cost (LCC) model. The research then aims to apply this model by analysing data from bus operators to create a comparative study of the dominant bus bodies in the market. Ultimately determining which bus body offers the lowest LCC.

2.1 Research Question

How do Volgren buses compare to other buses in the market on a basis of life cycle cost?

2.2 Methodology

The project reports on observable phenomenon. To do this, two stages of research are conceived. The first is the construction of a robust, accurate, comparative LCC model of bus bodies in the Australian route bus industry. This model is based on the Australian Standard model of Life Cycle Costing described in AS4536:1999 (Standards Australia 2014).

The second phase of the research is to use the LCC model to analyse data from bus operators. Several bus operators were contacted in the course of this research and provided data on a confidential basis. Operators have provided data on several buses within their fleets which creates several levels of analysis. Firstly the research will reflect a different LCC for buses within the same depot, based on the vehicle characteristics. It is also expected that the differences between depots will result in different LCC results. The research therefore takes some care to differentiate between differences at bus-level, depot-level and operator-level when comparing Volgren bodies to others.

2.3 Sample

A sample of buses was made across several Australian states and operating companies. The breadth of the sample provides validity for several of the model's fixed data points, for example the average number of incidents requiring repair. Within the study, only certain comparisons are made to answer the research question as some cost generating elements do not differ amongst the alternative bodies studied.

At time of writing three participating operators and four depots have been able to provide data for the model. Of the three, one can be observed to only have Volgren bodied buses, whereas others have varied fleets. Nine buses are included in the study so far, of which five have Volgren bodies. Table one categorises the different buses, bodies, chassis, operators and depots in the research.

Table 1. Operator, depot, bus sample, chassis and body (either Volgren or other).

Operator	1		2				3			4
Depot	Z		Y			X	W			
Bus	A	B	C	D	E	F	G	H	I	J (HYP)
Chassis	i	i	ii	iii	iii	iv	v	v	v	v
Body	V					V	V	V	V	V

Data were provided from operators which represent one year of each nominated buses life. This data has been extrapolated to form a model of the whole life of the bus. Some cost generating elements in the model are once-off activities and these have been represented as such.

2.4 Data source
There were two primary methods of data collection in the research. Numerical data were provided on request from bus operators. The operators are not identified in this report. The numerical data were found not to represent the necessary nuances of operation to form a satisfactory LCC model, and so the data were followed up with telephone and in-person interviews. The interviews revealed a range of behavioural characteristics which were then loaded into the numerical data to represent real-life operation.

2.5 Terminology
The term "study" is used in this report to refer to the task of comparing LCC of bus bodies, in which the model is the key tool. The term "comparison" is used with reference to particular buses that are in the study. For reasons explained in Section 3, only certain comparisons may be drawn so as not to compare bus bodies where external factors will create a difference in cost.

2.6 Methods
The ideal LCC model accurately represents the characteristics of its subject matter, while not covering unnecessary or irrelevant detail. To this end AS4536 is used as a basis for the new LCC model for the bus industry covering four main life cycle stages. Acquisition, use and maintenance, renewal and adaptation, and disposal. The standard recommends the following LC phases for inclusion in the research:

2.6.1 Acquisition
Purchase is the only differentiating activity used in this study under acquisition. Buses are purchased through a variety of means, from a simple purchase model to lengthy tender processes used for longer, larger contracts of supply. These are essentially the same for any bus body, although nuances in the process could be exploited by tendering organisations and respondents to reduce costs and create competitive advantage.

2.6.2 Use and maintenance support
Most detail in the study falls into this category. There are frequent, relatively inexpensive cost generating elements which add up over a 20 year life span, and also infrequent and one-off activities which carry significant costs. Some of the cost generating elements are easily studied by means of direct data, whereas others are determined by understanding the behaviours of the various depots and operating companies.

2.6.3 Renewal and adaptation
The long LC of buses can include major renewal works in a mid-life refit. Importantly, this high-cost activity is not always carried out. Adaptation works are rarer, and are usually the result of a wider improvement programme for example the implementation of a new ticketing system.

2.6.4 Disposal
Disposal generates a small amount of revenue, far disproportionate to the overall LCC. This in part leads to a reluctance to dispose of buses as a fully depreciated vehicle may still generate some small amount of service revenue towards the end of its life.

To populate the LCC model, a brief literature survey was conducted to create a first pass of potential data items. This review included two key texts in the transport planning field (Vuchic 2005, Vuchic 2007), other life cycle studies conducted in the bus industry (Ally and Pryor 2007, US Department of Transportation N.D.) and the relevant standard (Standards Australia 2014). From here a draft model was created and reviewed with Volgren and a bus operator. It became apparent at this point that some items in the model would be subject to judgement, some to a cross-section of the bus industry, and some from other data sources.

Once the model had been constructed, data were requested from bus operators.
Government reporting requirements of these operators serves to validate the accuracy of the data supplied to this research. The nature of the project also serves accuracy in two ways. Firstly that in giving data to this project the operators will be provided with the results of the study on their own buses, therefore serving to offer insights to the operator for their participation. Secondly, the data are dealt with confidentially and as such any inaccuracy in the data would not serve the operator with any benefit. A conclusion is drawn to implicitly trust the data used in the model.

Finally, figures are reported from the model in order to draw a direct comparison between buses with a Volgren body and those without. Depot differences are reported to identify where buses may be subject to LCC implications as a result of operational, or business, differences.

3. LCC model and data
A summary of the LCC model is presented, describing each of the cost and revenue generating activities analysed over the life of a bus. This section describes data sources, any assumptions made in the model, where estimates were used, and the method of accounting for the time value of money.

3.1 Background
The LCC model is grounded with the notion that a bus is purchased as a revenue generating capital good, and that the reliability and fitness for purpose fit the business practice of the operating company. Interviews in this study show that while operators are generally risk averse with regard to vehicle reliability, there remains a significant, observable, difference in the manner by which buses are operated in revenue service. These differences are caused by matters as diverse as contract arrangements, business history and culture, and local geographical idiosyncrasies. The role of public transport also leads to some politicisation at local, state and federal levels, with political engagement, political cycles, and how marginal a particular political tenure may be all having some effect on operations.

This research does not account for the definition of product (bus) need by the operator. While the details described below show that there are many cost generating activities and related cost saving opportunities, the provision of bus based public transport is a mature industry and therefore the definition of need for a bus is not a variable in this research. In addition, the research is studying real vehicles that are in service, based on data from their operation, so a high degree of certainty is claimed for this research. The LCC method outlined in AS4536 can also account for speculative product designs and so this study may find use for bus operators who are wishing to compare LCC prior to purchase.

This research is based on the assumption that any of the buses studied are compliant with the contracts of their operators. They are expected to offer compliant levels of comfort, safety, convenience and reliability for passengers and staff. It can be observed that different bodies, chassis and designs meet standards in different ways, some of which may be more pleasing than others, and some which may do far more than basic compliance. The research does not account for these except where there is an implication on LCC, for example in mid- life refit.

The identification of the cost generating elements detailed below was carried out through a literature review, a basis on AS4536, and interviews with bus operators. Data sought for the research are identified below.

Bus Description
- Annual insurance premium
- Annual VKT
- Bus body
- Bus Mass KG
- Chassis
- Licence Plate
- Life cycle (years)
- Operator Source

Acquisition
- Capital cost-$/bus

Use and Maintenance
- Fuel usage-Litres/100km
- Average annual KM at depot
- Corporate Overhead
- Cost of major repair per event
- Cost of minor repair per event
- Depot labour rate-$ p.hr
- Fuel rate- $/Litre
- Hours of Annual services
- Hours of Major services
- Hours of Minor services
- Improvements- $/yr

Use and Maintenance (cont'd)
- Mid life refit $/hr
- Mid life refit hours
- No. of annual repairs - major
- No. of annual repairs - minor
- Spare bus ratio-% of capital cost
- Structural inspection cost-$/hour
- Structural inspection lifetime hours
- Tyre usage-$/km

Renewal and adaptation
- Improvements

Disposal
- Disposal value $

3.2 Bus Description

A range of identifying materials were collected in the research in order that the vehicles studied could be found for further research as may be needed. To maintain confidentiality these are not reported here.

3.2.1 Bus Body

Bus Body is the focus of this study. Four different body marques were included in this research. Disclosure of the body types would make identification of particular depots possible in the data so a letter has been used to represent different bodies. Volgren bodied buses are identified in the study. Individual buses are represented by a letter in the model. Of particular interest will be buses A and B which share as many functional and operational characteristics as possible, with the key exception of bus body.

3.2.2 Operator

Bus operators participated in the research on a voluntary basis, after being contacted by the author. Participation was on the condition of confidentiality and as such the name and location of the operator is not used in this report. Importantly, the operator companies are listed in the data table in order that fair comparisons are drawn. In particular operator 2 provided data from depots Y and X across which care must be taken in comparison. In total four operators have participated so far in the study.

3.2.3 Chassis

Chassis type has the potential to be another significant determinant of LCC. An effort was made to control for the chassis type by studying buses of different body but with the same, or as similar chassis as possible. For example, in the model, buses 4 and 5 have different bodies but the same chassis. Care must be taken when comparing buses in the model to ensure that fair comparisons are made.

3.2.4 Bus Mass

Bus mass was reported by operators and has been taken directly from records, not from actual measurements. A degree of inaccuracy is expected in this data and future work should include field measurements of the actual vehicles in the study. It is the experience of the author that inaccuracies in reporting bus masses are common in the bus industry and the research team seeks to verify mass data as soon as is practical.

Bus mass will affect several LCC calculations. Tyre wear will be greater for a heavier bus. Fuel consumption will also be higher as discussed below under fuel use.

3.2.5 Life Cycle Length

Reported life cycle length varied between 20-25 years. The reported figures are used for life cycle length, with some variation across the model. In discussions with operators, the issue of LC length was found to have particular nuance. Depots may keep buses for longer than
20 years, depending on condition of a particular vehicle, contract length, and also to maintain a higher spares ratio at little cost. A depot may also store old vehicles if space permits, to use for lucrative rail replacement service contracts.

Three types of obsolescence are identified in the literature which will affect an operator's decision to dispose of a vehicle. Paraphrased below from Vuchic (2005 p327):
Physical life – ends when the vehicle cannot provide acceptable service in reliability or maintenance.
Functional life – ends when the vehicle is obsolete, although this can simply trigger an upgrade programme. Functional life is rare as most mandated upgrades are phased in to reduce waste.
Economic life – ends when the lowest life cycle cost is achieved.

The interplay of the three types of LC can be observed in the behaviour of bus operators. Physical life is probably the most significant determinant of the actual LC of a bus in the present Australian operating environment, with most vehicles exhibiting a level of wear and tear no longer acceptable for service at around 20-23 years. At this age, the

economic life is beginning to cross over into positive cost with rising maintenance and unreliability running counter to the profitability of operating a depreciated asset in revenue service.

LC length is a key determinant of LCC and future work using the model could investigate the impact of different LC lengths on LCC, as well as vehicle design. Different LC lengths could be nominated in the LCC model to investigate the impact of nominal economic life spans.

3.2.6 Annual Vehicle Kilometres Travelled
Annual VKT is recorded for vehicles and is another key determinant of LCC. VKT are used in the model as they are a driver of several costs. As such, the LCC model results offer a normalised LCC per KM to adjust for this. Annual VKT data are provided by bus operators, reported in the range of 27,902-81,891 KM/Year, these figures are also similar to literature reporting a range of 50,000-80,000 (Helms, Lambrecht et al. 2003). In contrast, the ABS reports an average VKT for all Australian buses (including school buses and coaches) of only 28,900 KM/Year (Australian Bureau of Statistics 2014)

3.2.7 Insurance
Cost of insurances for buses fall into either CTP or Comprehensive. In both cases there are no reported differences for insurance costs by bus body. Operators reported that depots have blanket insurance policies, the costs for which are determined by the value of the buses in the depot. A midi bus would have a lesser share of the premium than a 12.5M bus, but there is no difference in the body. This item has not been used as an element in the LCC.

3.3 Acquisition

3.3.1 Capital Cost
Capital cost was reported by participating bus operators with reference to their fixed asset registers. The capital cost was reported in dollars to the date of purchase. The cost of the finance to raise this capital is discussed below. Several buses in the study were purchased secondhand.

3.3.2 Discount rate
AS4536 Nominates a cost of capital rate of 9%PA. This figure was refuted by the research team as the interest rate at time of writing was 1.5% (Reserve Bank of Australia 2016). The RBA cash rate last crossed this figure in the 6th of November 1991 rate cut from 9.5% to
8.5%. The Bus Association of Victoria recommended using the 5 year swap rate as a more reliable index for the discount rate applied in bus finance.

For the purposes of this report annual operating costs were not discounted to current year dollars. Discounting was not applied as the data provided by bus operators were average costs per year to run a particular bus type. Therefore, for a particular model of bus year-to- year costs did not vary. By not discounting costs we will not affect the overall results in determining relative ranking of the LCC of Volgren buses relative to other buses, but it will amplify the magnitude. In future iterations it would be preferable if actual data costs could be provided on a yearly basis for each model of bus an operator is running. If such actual data were provided it would be necessary to discount different years costs to current year terms.

3.4 Use and Maintenance

This section provided the majority of the cost generating activities, and also the most difficulty in obtaining reliable data. Repairs and refit are the greatest source of differentiation between bus bodies. The information below and in the model reflects physical characteristics such as body materials, and behavioural characteristics of bus operation such as the willingness to refit vehicles and the tendency to allocate lump-sum costs to all vehicles in a depot despite differences.

3.4.1 Tyre Usage
The regularity of tyre replacement is affected primarily by VKT and mass. Operators have reported a tyre cost per KM. VKT is used to calculate the cost, which is then adjusted in the results under LCC per VKT.

Operators 1 and 3 reported tyre costs, but these are averaged over the depot not recorded on a bus-by-bus basis.

3.4.2 Structural Inspection
Structural inspection refers to one of the safety inspection procedures, aiming to determine any faults within the bus body. The legislation falls under state regulation so the National Heavy Vehicle Regulation Manual (National Heavy Vehicle Regulator 2016) and the Vic roads Vehicle Standards Information can be followed as a guide.

The inspection consists of a visual test of the structure in question. This can include simply viewing an external structural frame design or having to strip the outer panels to view an internal structural frame design, as corrosion may be hidden (Vic Roads 2012). Herein lies a potentially significant differentiator of bus body LCC.

Victoria's legislation states that this inspection must be undertaken annually (State of Victoria 2009). Further inspection details are found within Bus Safety Victoria (Bus Safety Victoria 2012) and Vic Roads vehicle standard information, regarding any condition that might affect performance or lead to structural failure, including "cracks, damage, faulty repairs or modifications, rust, deterioration, distortion" (Vic Roads 2012). In contrast the Queensland legislation (Transport Operations (Passenger Transport) Standard 2010) states that this process is undergone between 20-21 years of age, looking again for signs of weaknesses or a satisfactory condition (State of Queensland 2010).

Operators reported that annual safety inspections include a minor body inspection, but a major structural inspection is carried out once during the bus LC at 25 years of age, and thus is sometimes not carried out at all.

Further inspections of the bus structure are notably triggered when accident repairs are undertaken. For a bus to be made good, the structure must be sound. During accident repair it was reported that structural issues are discovered that were not caused by the accident in question. Nevertheless repairs must be made, and this can be a significant cost. In
particular, when removing the body panels of a steel bodied bus, participants reported the discovery of rust which must be removed. Hence the structural inspection costs are not fully represented under this item, but in the cost of major repairs.

3.4.3 Mid-Life Refit
Mid life refit seeks to return an aging bus to as-new condition. The refit consists of a range of interior and exterior visual refresh works such as new upholstery, floor vinyl, a steam clean, fixing minor water leaks and removing graffiti. Some extent of drivetrain work is also undertaken usually with a reconditioning of the engine and transmission.

Approaches to mid-life refit differ across operators. Cost of a mid-life refit is comprised of several components, for example whether it is carried out at all, how many times it is done, and the extent of works for each instance.

One operator reported that their contract environment resulted in no need to conduct a refit, however this operator only used Volgren bodied buses and indicated in interviews that they would have to conduct a mid-life refit if the bodies were from another manufacturer. This is a significant cost difference however the actual cost difference is unknown.

Another operator reported that all their vehicles are re-fitted at around 12-15 years, and that Volgren bodied buses are usually refitted for a cost rarely exceeding $20,000. Rust issues usually meant that any comparable steel bus would fetch a refit cost of $30,000 with some as high as $40,000.

3.4.4 Servicing
The nature and frequency of servicing is observed to be at the discretion of the operating company and individual depot. Interviews with fleet managers indicate adherence to best practice for preventive maintenance which maintains the dependability of vehicles. There is little appetite for risk with regard to reliability. The reported service schedules and hierarchy from operators are aligned with broadly accepted theory (Vuchic 2005 p313).

The reliability of different bus bodies is of some interest in the industry, but no robust data were available to measure this factor in this study. Further work on reliability would be of use to this LCC study but the differences may be marginal compared to other cost generating activities.

Service intervals are determined approximately by VKT. A 7500KM interval was reported by two operators, with every 4th minor service being a major service, and also one service per year being an annual service. Annual servicing appears to be triggered by calendar year, however it is also conducted in place of a minor service, at the relevant interval. Because of
the variance in VKT the service costs are compared in the model my means of hours and a labour rate, in order not to double-charge for VKT. A bus that is easier and therefore less time consuming to service will carry a lower cost.

Operator 2 did not provide data on servicing.

3.4.5 Repair – major and minor incidents
Accident repairs are diverse. In order to calculate the cost impact of accidents two categories of accident were created, minor and major. Minor is characterised by low speed traffic accidents requiring replacement of non-structural parts such as bumper elements and lamps. Major repairs add structural work to this.

Representative data were needed to accurately characterise the different repair costs of identical, or very similar collisions, which were not provided. Interviews revealed a willingness to discuss minor and major repairs and so the basic categorisation was used in the model. Repair data were only provided by operator 1 and so the comparative cost of repair is only studied across buses A and B.

Aluminium bodied buses were reported to have higher minor repair costs in the first few years of life. This cost is driven by the higher cost of specialist labour for aluminium work. After the first few years of life, this additional cost is offset by the presence of rust in a steel bodied bus, and then aluminium bus gets cheaper to repair than a steel counterpart. This difference is amplified for major repairs as discussed above in section 3.4.2. Based on this information, the model uses reported rough figures for the cost of repair as reported by operator 1 in broad figures:
Minor repair aluminium body over life: $4000
Minor repair steel body over life: $5000

3.4.6 Annual occurrence of incidents
The average number of minor incidents across the study is 0.5 per year. This average is used as a constant in the model so as not to unfairly cost one bus against another because of a particularly bad run. The cost of the incident is borne by the cost to repair variable.

Operator 1 reported the following broad figures to be representative of their fleet:
Annual occurrence of minor repairs: 0.5
Annual occurrence of major repairs: 0.1

3.4.7 Downtime and spares ratio
Any time a bus is taken off the road a cost is incurred by the operator in providing a replacement vehicle into service. Spare vehicles are needed in any depot to cover the time vehicles are serviced, repaired, or otherwise unavailable. This is a direct cost, and compounds the costs already borne in servicing for example. The hours for which a spare is required were accounted for in the LCC model, using the vehicle itself as a cost basis. This item requires more work as no differences were found relating to bus bodies. Spares ratio is affected by many other outside factors including but not limited to risk appetite, contracts for rail replacement, and to what extent the operator has insourced or outsourced repairs and maintenance tasks.

3.4.8 Improvements
Improvements were identified, as distinct from scheduled preventive maintenance, or incident repair, as a potential generator of cost. Interviews with depots indicated that improvements are very rare and that most buses will go through their life cycle with no improvements made. The most likely trigger of improvements are changes in safety standards or operating technology such as the implementation of new ticketing systems such as MYKI in Victoria and OPAL in New South Wales.

Buses A and B were subject to a major technology upgrade programme however the cost for this was borne by the contracting government authority and so costs were not recorded by the operator. 3rd party contractors carried out the work at no cost to the operator.

3.4.9 Corporate Overhead
Corporate overhead allocation methodology is potentially disruptive to the LCC model, in that care must be taken not to compare buses from different depots or operators which may have different allocation methodologies. To this end, the study compares costs of buses from the same depots and operating companies. Labour cost is the main avenue for this to be expressed in the LCC. Allocation of overhead is identified as an area of potential future research, in that cost savings and better accounting methods may achieve cost savings or efficiencies for the bus industry.

3.4.10 Fuel cost
Fuel cost is a constant and while the market fluctuates the LCC model assumes that all diesel fuel is purchased by operators for $1.05/Litre. This is contrary to one operator's book keeping figure of $0.95/Litre, but does reflect the following central data:

Australian Average Terminal Gate Price of Diesel, per Litre: At time of writing: $1.059
Average of last 12 months: $1.039
5 year average to time of writing: $1.300 (Australian Institute of Petroleum 2016)

3.4.11 Fuel use
Fuel use is a variable across different sampled buses. The primary impact on fuel use is the mass of the bus with other impacts being topography and driver. Inaccuracies in the reporting of bus mass are discussed above at section 3.2.4. To this end, different buses sampled have different masses, so judgement is required to sample

two or more buses that are functionally identical to the greatest extent possible, with the exception of bus body. One such sample is buses A and B with the same reported mass but the Volgren bodied bus having a 2.2L/100km saving in fuel use.

Once actual bus masses are obtained, a calculation could be used to determine the potential saving in fuel use. The relationship between fuel use and mass is not currently represented
in the model. Literature shows a fuel consumption saving of 0.15L/100KM/100KG of bus mass would be reasonable. That is to say, a 100KG saving in mass will save 0.15L of fuel for every 100KM of driving. This information is an average of the 0.1-0.2L/100KM/100KG estimated by the Institute for Energy and Environmental Research (Helms, Lambrecht et al.
2003) and is accepted by the International Aluminium Institute (Alcan and Rusal 2008) and the European Commission on Climate Action (Hill, Norris et al. 2015).

3.4.12 Annual KM
Annual Vehicle Kilometres Travelled (VKT) was reported by operators for all buses with the exception of bus F, for which a nominal figure of 40,000 has been inserted based on the operator's other vehicles.

VKT is a major determinant of LCC and as such the results include LCC per KM to account for this difference.

3.5 Disposal
Similarly to LC length, varied data were collected at this item. The disposal value of a bus is low, and is generally tied to the scrap value of the metal inside. This is tempered by how easily that metal may be extracted by a salvage yard, and as such a lower sale price is achieved. Although the raw metal value of a vehicle will vary by type and quantity of metal to be found inside, there is little recognition of this in the scrap market, perhaps reflective of the relatively high labour cost to extract it.

Disposal prices were discussed in interviews with operators. The majority of buses are sold for scrap at process between $1100 and $2000 depending on market forces and geographical location. Higher prices can be fetched at times in the second-hand market but this is reported as very rare.

3.5.1 Scrap Value
Quantity and type of metal will have some bearing on the scrap value of a bus, however the effect is somewhat damped by the labour necessary to extract it. Prices for scrap metal were observed to be variable, but reported as follows:
Aluminium $1.4/kg, Steel $.06/kg (Carri 2016).

This Aluminium trend seems to be slightly positive according to the previous 10 year prices, which have fluctuated within a range of US$0.80 - US$1.40 according to KITCO metals, this historical information is not for scrap metals which must be considered (Kitco 2016).

The two most common materials, steel and Aluminium have significantly different purchase prices, with the London Metal Exchange prices at time of writing:
Aluminium: US$1.573/kg, Steel: US$0.325/kg .

4. LCC model findings and analysis

The results obtained from the data and model are not absolute, but relative. They do not offer a complete LCC of operating a bus, as this is outside the aim of this research. The LCC model provides a comparative study into the cost generating activities that differ by bus body.

Figure 1. LCC per KM for buses studied, average, and hypothetical case J.
Key to colours: Volgren Other Average
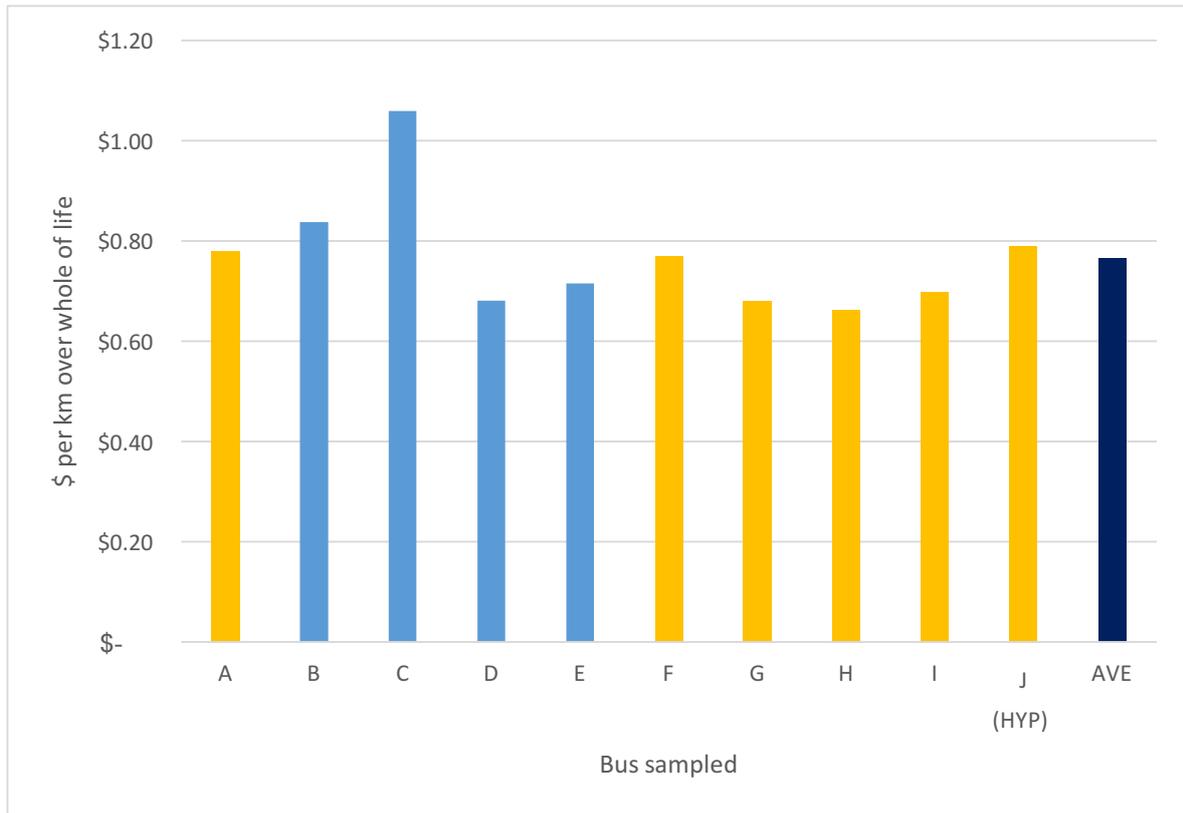
Table 1. Data inputs.

	Source	A	B	C	D	E	F	G	H	I	J (HYP)
Operator		1	1	2	2	2	2	3	3	3	4
Depot		z	z	y	y	y	x	w	w	w	v
Bus		A	B	C	D	E	F	G	H	I	J (HYP)
Bus Description											
Chassis		i	i	ii	iii	iii	iv	v	v	v	v
Body	Bus	Volgren					Volgren	Volgren	Volgren	Volgren	Volgren
Bus Mass KG	Operator	11,060	11,060	18000	18000	17800	19100	11200	11200	11200	11,060
Life cycle (years)	Operator	25	25	25	25	25	20	20	20	20	20
Annual VKT	Operator	63,750	61,827	29642	27902	40557	40000	73834	81891	75681	63,750
Annual insurance premium	Operator	6419.49	6419.49								6419.49
Acquisition											
Capital cost-$/bus	Operator	428,944	433,028	500,500	240,000	334,000	296,780	264,000	264,000	264,000	428,944
Use and Maintenance											
Fuel usage-Litres/100km	Operator	40.2	42.4	34.03	29.34	34.91	43.19	41.84	42.07	43.97	40.2
Tyre usage-$/km	Operator	0.0334	0.0334	0	0	0	0	0.0327	0.0327	0.0327	0.0334
Structural inspection lifetime hour:	Operator			1	1	1	1	0	0	0	
Mid life refit hours	Operator	500	750	500	500	500	500	0	0	0	0
Hours of Minor services	Operator							28	28	28	
Hours of Major services	Operator							14	14	14	
Hours of Annual services	Operator							16	16	16	
Cost of minor repair per event	Operator	4000	5000					0	0	0	
Cost of major repair per event	Operator	8000	12000					0	0	0	
Improvements-$/yr	Operator	0	0					0	0	0	
Corporate Overhead	Operator	0	0					0	0	0	
Disposal											
Disposal value-$ scrap	Operator	1100	1100					2000	2000	2000	1100
Use and Maintenance											
Depot labour rate-$ p.hr	Operator	47.50	47.50	29.46	29.46	29.46	29.46	38.988	38.988	38.988	47.50
Fuel rate-$/Litre	Bulk terminal rate ave.	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05
Mid life refit $/hr	Operator	40	40	40	40	40	40	0	0	0	0
No. of annual repairs - minor	Operator	0.5	0.5	0	0	0	0	0	0	0	0
No. of annual repairs - major	Operator	0.1	0.1	0	0	1	4	0	1	0	0
Structural inspection cost-$/hour	Operator			218.01	218.01	218.01	218.01	0	0	0	0
Spare bus ratio-% of capital cost	Operator	9	9					0	0	0	
Average annual KM at depot	Operator	49000	49000								

Notes:

Cells shown in blue are awaiting expected data. Purchase price for buses D and F are second-hand. Annual VKT for bus F is nominal not reported. Refit hours for buses A and B are reported averages from operator across fleet. Depot labour costs for operators 1 and 3 include on-costs. Operator 3 reported a higher disposal value as shown.

Table 2. Results.

Operator	A	B	C	D	E	F	G	H	I	J (HYP)	AVE
(No.)	1	1	2	2	2	2	3	3	3		
Depot	Z	Z	Y	Y	Y	X	W	W	W		
Bus	A	B	C	D	E	F	G	H	I	J (HYP)	AVE
Chassis	i	i	ii	iii	iii	iv	v	v	v	v	
Body	Volgren					Volgren	Volgren	Volgren	Volgren	Volgren	
Acquisition											
Capital cost	428,944.00	433,028.00	500,500.00	240,000.00	334,000.00	296,780.00	264,000.00	264,000.00	264,000.00	428,944.00	336,139.11
Total	428,944.00	433,028.00	500,500.00	240,000.00	334,000.00	296,780.00	264,000.00	264,000.00	264,000.00	428,944.00	336,139.11
Use & Maintenance											
Annual KM	63,750.00	61,827.00	29,642.00	27,902.00	40,557.00	40,000.00	73,834.00	81,891.00	75,681.00	63,750.00	55,009.33
Fuel cost	26,909	27,525	10,592	8,596	14,866	18,140	32,437	36,174	34,941	26,909	23,353
Minor Service costs	-	-	-	-	-	-	1,092	1,092	1,092	-	364
Major Service costs	-	-	-	-	-	-	546	546	546	-	182
Annual Service costs	-	-	-	-	-	-	624	624	624	-	208
Tyres	2,129	2,065	-	-	-	-	2,414	2,678	2,475	2,129	1,307
Repairs-minor	2,000	2,500	-	-	-	-	-	-	-	-	500
Repairs-major	800	1,200	-	-	-	-	-	-	-	-	222
Structural inspection	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	-	-	-	-	-	-	-
Annual Use and Main. Cost	31,838	33,290	10,592	8,596	14,866	18,140	37,112	41,113	39,677	29,038	26,136
Projected Lifetime total	795,953	832,260	264,788	214,894	371,659	453,495	742,249	822,265	793,537	580,763	587,900
Renewal & Adaptation											
Improvements	-	-	-	-	-	-	-	-	-	-	-
Once off Refit	20,000	30,000	20,000	20,000	20,000	20,000	-	-	-	-	14,444
Total	20,000.00	30,000.00	20,000.00	20,000.00	20,000.00	20,000.00	-	-	-	-	14,444.44
Disposal											
Salvage value	1,100.00	1,100.00	-	-	-	-	2,000.00	2,000.00	2,000.00	1,100.00	1,640.00
Total	1,100.00	1,100.00	-	-	-	-	2,000.00	2,000.00	2,000.00	1,100.00	1,640.00
Life Cycle Cost	1,243,797	1,294,188	785,288	474,894	725,659	770,275	1,004,249	1,084,265	1,055,537	1,008,607	937,573
LCC per KM	0.78	0.84	1.06	0.68	0.72	0.77	0.68	0.66	0.70	0.79	0.76

4.1 Overall comparison

Based on the most robust comparison offered by buses A and B, and all other characteristics being equal, the Volgren bodied bus has the lowest life cycle cost. The comparative figures used in this research show the Volgren bodied bus to have LCC/KM 7.3% lower than the non-Volgren.

Based on Annual VKT of 62,000KM, a lifetime saving of $36,000 is made in fuel by the Volgren. A lifetime saving of $10,000 is made through repairs, and another $10,000 through savings in refit costs, mainly caused by the incidence of rust in bus B. A further one-off saving of $4084 is made in the lower capital cost of the Volgren.

Buses A and B present the best comparative case. Buses C-I strengthen this comparative case by corroborating evidence around cost generating activities, for example refit cost. Buses G-I are almost entirely identical in vehicle and operation, as well as body, and serve the model as evidence for some costs, but also to represent behavioural aspects of this research which reduce costs – in particular that operator 3 does not carry out a mid-life refit.

4.2 Other findings

Interviews with bus operators and their reported data found some pertinent issues outside the main scope of this research. The relationship between life cycle cost and life cycle length is worth consideration in the industry. Specifically, based on the model and data, buses G,H and I exhibit the lowest life cycle cost. When the data are interrogated, the LCC/km is achieved even though G, H and I account for service costs and bus A, also a Volgren, does not. When the repair costs are removed from bus A, it is still more expensive to operate. A saving of $0.02/km over the life of the bus is saved by through an LC length of only 20 years, and additionally not carrying out a mid-life refit. These figures are represented by bus J, which is a hypothetical vehicle combining characteristics of buses A and I in the research.

5. Discussion

This report should be of use to bus manufacturers and operators. It may shed some light on particular cost-generating features of the vehicle, or its operation, representing opportunities for cost reduction. The most substantial differences between bus bodies were found in use and maintenance, and are primarily driven by bus mass and resulting fuel use. The incidence and cost to repair rust damage was the second major driver.

AS4536 raises a discussion concerning how much LCC is fixed at various stages of a product LC. As time elapses, proportionately more of the LCC is already fixed into the future, and a substantial proportion of the LCC is actually fixed in the product design phase. This is corroborated by this research showing that the major differentiators of LCC are bus mass and body materials. This may inform product development to reduce LCC.

Buses C-F from operator 2 have fewer annual kilometres in their duty cycle. No data were supplied for these vehicles service or repair characteristics, but the model still reveals that the mid-life refit allocation for these vehicles is a greater proportion of their total LCC. The allocation of the nominal $20,000 for refit by operator 2 may also be reasonably reviewed, as some buses may need more or less. Indeed operator 3 reports that a refit is not necessary for their Volgrens if the LC length is set at 20 years. The five year difference from 20-25 is more substantial than the 25% additional LC length it represents. At the end of the buses life, a greater number of more substantial issues are likely, so the additional five years of LC length may actually be a false economy. This is all the more likely if a refit is not necessary on a 20 year LC.

5.1 Limitations and further work

The data in this research were provided on a voluntary basis by bus operators. In time, more participants can be recruited and more buses studied from existing participants. There is a strong level of certainty in the results of this research, as interviews with separate bus operators in different states have shown the various factors to be in alignment.

It is proposed that this research is a starting point for a better understanding of LCC in the bus industry. Given the complexity of the equipment and operations an absolute study may not be feasible. More detail on servicing and repairs would be a welcome addition to the existing work.

Behavioural characteristics differ greatly between the operators in this research. In the pursuit of lower overall operating costs, further work could be undertaken to study how a sample of buses progress through their life cycle. Such a longitudinal study would take years to reveal any useful information but given the 20 year lifespan of a bus may be a worthwhile exercise.

6. Conclusion

By employing a life cycle cost model with data from bus operators, this research conducted a comparative study of different bus bodies in order to determine how Volgren bodied buses compared with others on the Australian market. Nine vehicles were studied across three operators and four depots. Cost generating activities were included in this research if they were a determinant of difference in cost. Many cost generating factors are not differentiated by bus body and many others may be but are not recorded by operators. One major comparison was made between near-identical buses, with data corroborated through the other seven in the study. On the basis of this study a Volgren bus offers a lower life cycle cost, with a 7.3% difference in the Life Cycle Cost per KM across the cost generating elements studied. Body structure design has the largest impact within the elements studied, with cost savings tied to the materials used in the body, reparability, avoidance of rectification work in the structure and in some observed cases the ability to achieve substantial savings in mid-life refit. Fuel use reductions, achieved through a lower vehicle mass, also had a substantial influence in reduction of life cycle cost.

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