WORKING PAPER
ITS-WP-99-2

How are Urban Bus Fleets Performing in Reducing Greenhouse Gas Emissions? The Australian Experience

by

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January, 1999

ISSN 1440-3501

Established and supported under the Australian Research Council's Key Centre Program.

INSTITUTE OF TRANSPORT STUDIES
The Australian Key Centre
in Transport Management

The University of Sydney
and Monash University

NUMBER: Working Paper ITS-WP-99-2

TITLE: How are Urban Bus Fleets Performing in Reducing Greenhouse Gas Emissions? The Australian Experience*

ABSTRACT: The transport sector is a major contributor to greenhouse gas emissions. Although the bus operator is a small player in the emissions stakes, the entire life cycle emissions from the manufacture of buses and diesel fuel is a significant contributor to CO_2.The consequences of the move from manual to automatic buses is that we are seeing a noticeable increase in emissions, even though automatic transmissions are themselves becoming increasingly more environmentally friendly. This paper reviews the evidence in Australia based on a 1998 survey of over 1400 buses. The challenge is to find ways of reducing CO_2 emissions of automatic buses as they replace manual buses in similar operational contexts without increasing the amount of emissions.

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DATE: January, 1999

**This paper is part of contribution from ITS to a Greenhouse Challenge Unit Study of the Bus and Coach Sector.*

Sources of Greenhouse Gas Emissions

The transport sector as a whole contributes 25% of all greenhouse gas emissions (Raimond and Hensher 1994). Bus and coach operators are minor players in the transport task, contributing about 2 percentage points of the transport sector’s emissions. As end-use service suppliers, the bus and coach operators contribution to greenhouse gas emissions is about 0.5 per cent. This is attributable to total fuel consumption of 378 mega litres (i.e. millions of litres) in 1994/95 comprising 361 ML of diesel and distillate, 10 ML of CNG and 7 ML of LPG. 66.9 per cent of all fuel is consumed in urban bus and coach activity and 90.7 per cent of all fuel is diesel or distillate (Apelbaum 1997, Table V.3). Added to this however are indirect sources of emissions through the full emission cycle in manufacture. It is estimated that the direct (fuel) emissions represent 1.22 Mt CO_2-e and indirect emissions 5.8 Mt CO_2-e (Lenzen 1997).

Indirect emissions arise from fuel production, from operating and capital expenditure of transport industries and private households, and from expenditure of the government sector on the transport system such as construction of infrastructure. Lenzen (1997) has recently calculated the indirect contributions using an input-output model of all sectors in Australia. The indirect sources of greenhouse gas emissions (defined by CO_2 and the other emittants in CO_2 equivalent units) attributable to all activities in the supply chain that produce inputs into the delivery of bus and coach services - especially the vehicles, the fuel and the infrastructure - are 4.75 times the magnitude of the end-use emissions.

This ratio is sufficiently large not to ignore and suggests that the greatest gains in terms of reducing greenhouse gas emissions are likely to come from improvements in fuels and vehicle technology. Lenzen (1997) suggests that 4.3/4.75 or 90.5 per cent of the indirect contribution to greenhouse gas emissions is from the production of fuel - coal, oil and gas extraction, oil refining, gas distribution, and electricity generation.

While there is an opportunity for bus and coach operators to make a contribution to meeting the challenge to reduce greenhouse gas emissions, there is little scope for them to contribute without availing themselves of more environmentally cleaner vehicles and fuel technology. While it is recognised that bus and coach operators can also contribute in a non-marginal way by trying to increase their share of the total passenger kilometres, it is unlikely that there will be significant increases in market share even though the growth of bus and coach travel will increase over time.

Button and Rothengatter (1997) reinforce the widespread view that policies designed to attract significant numbers of travellers to switch from car to public transport by improving the quality or, through subsidies, by reducing the financial costs of using the public modes have not, in practice been conspicuously successful. Recent UK simulations indicate that staged reduction of public transport fares, so that by 2021 such fares are only 20 per cent of their 1992 level, would reduce carbon emissions by just over 1 per cent by 2000 and just over 3 per cent by 2025 (Acutt 1996). The car is likely to remain the dominating mode and lose very little if any share to public transport in general and buses and coaches in particular, over the next 20-30 years. Similar findings have been found for Australia by Hensher (1998).

The aim of this paper is to take a closer look at the greenhouse gas emissions efficiency of the existing bus fleet in Australia, establishing the extent to which the replacement of older vehicles with younger vehicles is contributing to reducing greenhouse gas emissions. We are particularly interested in the contributions, segmented by role, of vehicle age, utilisation, transmission and make.

Sources of Influence on Bus Emission Reductions

Greenhouse gas emissions are directly related to the fuel consumption of buses and coaches and their rate of utilisation. If the fuel consumption of buses and coaches is measured in litres per 100 km (ideally for the city and highway cycle), and we know the annual kilometres of vehicles in each age cohort, then assumptions can be made as to the likely impact on greenhouse gas emissions of accelerating the replacement of older vehicles with new or younger vehicles. An estimate of this is made for conventional fuels (primarily diesel). There are very few alternative-fuel vehicles in Australian fleets (exceptions being the State Transit Authority of Sydney who have over 100 CNG vehicles (Butler 1997 and Erdos 1998a, 1998b).

To provide some insights into the relationship between vehicle vintage, fuel efficiency and utilisation, a sample of 39 operators in urban NSW were requested to provide this information for each of their vehicles. These operators provide a significant amount of private bus service kilometres, close to 80%. Information was sought for each vehicle on make, model, year of manufacture, transmission, fuel efficiency, seating capacity, standing capacity, vehicle type (ie heavy route bus, medium route bus, dedicated school bus, mini-bus), estimated cost when manufactured, and estimated annual vehicle kilometres for period ending 30 June 1998.

Information on 1441 buses (45.2% manual (including semi-automatic) and 54.8% automatic) from surveyed operators was obtained. The information was used to investigate the relationship between full combustion end-use CO_2 emissions, vehicle age, transmission and utilisation. Tables 1 to 6 cross tabulate the information. On average, the automatic vehicles across all ages are less fuel-efficient and produce more end-use CO_2 emissions than the manual vehicles. Figure 1 graphs the average CO_2 emissions by vehicle age for each transmission type. It can be seen that the gap in terms of end-use CO_2 emissions from manual and automatic vehicles has widened over the last 12 years. In terms of the fuel efficiency and production of end-use CO_2 emissions with respect to vehicle make, on average, the Mercedes manual vehicles are the most fuel efficient and produce the least CO_2 emissions across all makes and transmission types. The Mercedes automatic vehicles are also the most fuel-efficient and produce the least CO_2 emissions amongst the automatic vehicles.

Table 1. Composition of the Bus Fleet by Age and by Transmission Type

Vehicle Age	Profile (Number and Percentage) of Fleet			
	Manual Transmission		Automatic Transmission	
	Number	Percentage	Number	Percentage
3 years or less	30	4.6	117	14.8
4 to 6 years	93	14.3	179	22.7
7 to 9 years	90	13.8	96	12.2
10 to 12 years	84	12.9	80	10.1
13 to 15 years	77	11.8	128	16.2
16 to 18 years	83	12.7	105	13.3
19 to 21 years	101	15.5	73	9.2
22 years or more	93	14.3	12	1.5
Total	**651**	**100.0**	**790**	**100.0**

Table 2. Fuel Efficiency by Age and by Transmission Type

Vehicle Age	Fuel Efficiency (*l*/100 km)			
	Manual Transmission		Automatic Transmission	
	Mean	Std. Deviation	Mean	Std. Deviation
3 years or less	25.87	6.58	36.30	4.87
4 to 6 years	24.75	7.09	36.56	6.20
7 to 9 years	28.58	8.64	41.04	5.37
10 to 12 years	35.67	6.28	40.79	4.45
13 to 15 years	36.91	6.43	41.16	6.43
16 to 18 years	38.40	6.61	39.57	4.48
19 to 21 years	37.15	5.16	42.19	7.49
22 years or more	37.95	5.06	38.63	4.42

Table 3. Fuel Efficiency by Make and by Transmission Type

Make	Fuel Efficiency (*l*/100 km)			
	Manual Transmission		Automatic Transmission	
	Mean	Std. Deviation	Mean	Std. Deviation
Hino	32.30	4.83	39.76	6.60
Mercedes	23.36	6.37	37.03	5.16
Volvo	32.38	4.34	40.20	3.85
MAN	36.27	3.53	37.39	7.03
Leyland	40.65	4.19	49.22	9.10
Others	31.17	5.82	38.67	7.60

Note: Others include Austral, Denning, Csepel, AEC, Bedford, Isuzu and Scania.

Table 4. CO_2 Emissions by Age and by Transmission Type

Vehicle Age	CO_2 Emissions (kg/1000 km)			
	Manual Transmission		Automatic Transmission	
	Mean	Std. Deviation	Mean	Std. Deviation
3 years or less	695.95	176.91	976.52	131.08
4 to 6 years	665.85	190.73	983.47	166.74
7 to 9 years	768.76	232.34	1103.94	144.46
10 to 12 years	959.61	168.89	1097.34	119.82
13 to 15 years	992.83	172.88	1107.12	173.08
16 to 18 years	1032.88	177.88	1064.37	120.49
19 to 21 years	999.39	138.93	1134.78	201.51
22 years or more	1020.87	135.98	1039.10	119.02

Table 5. CO_2 Emissions by Make and by Transmission Type

Make	CO_2 Emissions (kg/1000 km)			
	Manual Transmission		Automatic Transmission	
	Mean	Std. Deviation	Mean	Std. Deviation
Hino	868.98	130.03	1069.48	177.46
Mercedes	628.42	171.39	996.21	138.85
Volvo	870.95	116.83	1081.29	103.43
MAN	975.57	95.09	1005.69	189.09
Leyland	1093.46	112.65	1323.97	244.88
Others	838.39	156.52	1040.10	204.40

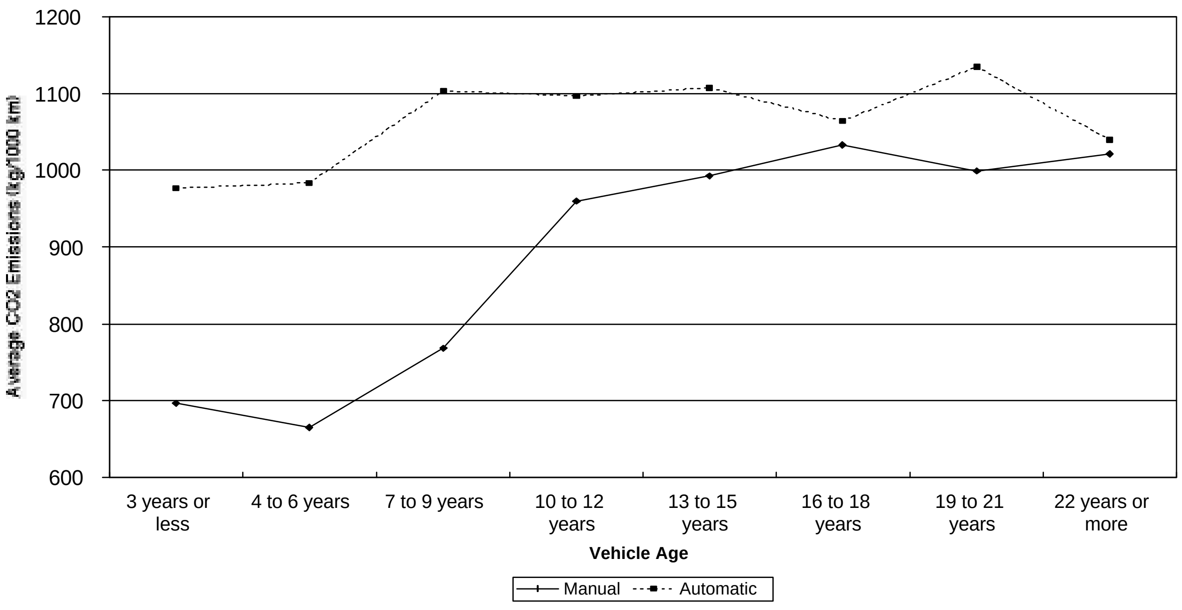
Note: Others include Austral, Denning, Csepel, AEC, Bedford, Isuzu and Scania.

Table 6. CO_2 Emissions by Vehicle Kilometre and by Transmission Type

Vehicle Kilometres per annum	CO_2 Emissions (kg/1000 km)			
	Manual Transmission		Automatic Transmission	
	Mean	Std. Deviation	Mean	Std. Deviation
Up to 20,000	1023.96	176.05	1077.65	244.92
20,000-39,999	968.07	176.86	1087.20	194.52
40,000-59,999	904.87	192.52	1069.28	159.34
60,000-79,999	774.49	229.27	1037.80	131.79
80,000 and over	563.75	121.87	980.87	128.44

Average annual kilometres are 39,990 for manual vehicles and 55,080 for automatic vehicles. Automatic vehicles consume on average more litres per annum: 14,833 litres, compared to 8,543 for manual vehicles; and are less fuel efficient - 39.3 *l*/100km compared to 33.7 *l*/100km for manuals. CO_2 emissions for manuals average 906 kg/1000 km and for automatics 1058 kg/1000 km., based on actual vehicle kilometres travelled.

Figure 1. Average CO_2 Emissions by Vehicle Age and by Transmission



A number of multiple linear regression models were estimated to identify the extent to which CO_2 emissions are related to vehicle age as shown by the direct elasticity of CO_2 emissions with respect to vehicle age for both manual and automatic vehicles. The results are summarised in Table 7. The carbon content of diesel is taken to be 2.69 kg/*l*. (Hensher et al 1995). The double logarithmic specification for all continuous variables provided the best statistical fit, as is often found in econometric studies.

Table 7. The Relationship between CO_2 Emissions, Vehicle Age, Transmission and Utilisation (t-values in brackets).
Dependent variable: natural logarithm (CO_2 per 1000 km).

	Model 1			Model 2		
Explanatory Variable	**Total sample**	**Manual**	**Automatic**	**Total**	**Manual**	**Automatic**
Constant	6.850 (149)	6.132 (151.1)	6.805 (395)	7.553(58.2)	7.051 (30.3)	6.952(47.4)
Natural log of age	.144 (18.1)	.2628 (17.7)	.0692 (9.4)	.1126 (14.5)	.2129 (11.5)	.0658 (8.8)
Natural log of vkm	-	-	-	-.0776 (-6.8)	-.0766(-4.0)	-.0129(-1.0)
Manual (1,0) dummy *	-.2255(-19.2)	-	-	-.2466(19.5)	-	-
Sample size	1471	649	822	1471	649	822
R^2	.309	.379	.089	.335	.399	.089
Dependent Variable:						
Mean	6.87	6.77	6.95	6.87	6.77	6.95
Standard deviation	.238	.277	.166	.238	.277	.166

* A bus with a manual transmission takes the value 1.0 for this variable and zero otherwise.

From Table 7, it is possible to derive a measure of the responsivenss of CO_2 emissions to changes in the age of vehicles. The CO_2 emissions elasticity with respect to vehicle age for all vehicles (manual and automatic) is .144 when vkm are not adjusted and .113 when allowance is taken of vehicle kilometres. That is, all other things being equal, a 1% increase in vehicle age leads to a .113% - .144% increase in CO_2 emissions. Working with an equivalence of 4% to 1 year of a vehicle's age, given maximum age of 25 years, we can suggest that for every 1 year increase in a vehicle's age, the CO_2 emissions increase by .452%-.576%. Thus a 10-year-old vehicle tends to have up to 5.76% more CO_2 emissions than a new vehicle.

When manual and automatic vehicles are distinguished, the age impact is very significant for both manual and automatic vehicles, but with substantially lower emission elasticities with respect to age (3.5 times lower) for automatic buses. This is an important finding suggesting, if generalisable, that the introduction of automatic vehicles to replace manual vehicles has reduced the CO_2 emissions differences across the vintage range, but this comes at a significant increase in the average CO_2 emissions per bus. The gap between CO_2 emissions for manual and automatics is widening substantially over time with newer automatics being much more emission unfriendly than their equivalent vintage manual vehicles (see Table 4 and Figure 1).

To see if any differences occur between vehicle makes, we ran a series of models with make-specific dummy variables. Some vehicle makes produce higher CO_2 emissions, for example, Leyland, Csepel, AEC, while others produce lower CO_2 emissions, for example, Mercedes and MAN. Vehicle makes such as Volvo (+), Isuzu (+), Scania (-) and Bedford (-) have no significant influence on variations in CO_2 emissions. The sign in brackets indicates a positive (+) or negative (-) statistically insignificant relationship between make and CO_2 emissions. It should be noted that AEC and Bedford are no longer purchased.

Conclusions

As the bus industry replaces manual vehicles with automatic vehicles, we will see a noticeable overall increase in CO_2 emissions. This is despite the fact that automatic vehicles over time are becoming more emission friendly. Automatic buses reduce CO_2 emissions by a much lower increment as we reduce their age by one year compared to manual buses. The ratio is close to 1:3.5. Bus operators who replace their automatic vehicles with automatic Mercedes and/or MAN chassis will see the most noticeable gains in end use CO_2 emissions, although this does not compensate for any circumstance where an automatic transmission replaces a manual transmission. The challenge remains - to find ways of reducing CO_2 emissions of automatic buses as they replace manual buses in similar operational contexts without increasing the amount of emissions. This will be quite a challenge given that manual transmissions produce CO_2 emissions that are typically 60-70% lower than those produced by automatic transmissions.

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