

# Relationship Between Road Track Cost And Heavy Vehicle Fuel Consumption

*Jamil I. Ghojel*

Department of Mechanical Engineering, Caulfield Campus, Monash University, Australia

*Harry C. Watson*

Department of Mechanical and Manufacturing Engineering, The University of Melbourne, Australia

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## ABSTRACT

The study looks at the fuel-only option to recover road resource cost from trucks. The main advantage of this scheme as a cost recovery mechanism is the minimum administrative and enforcement costs. The study examines the correlation between fuel consumption (litre/km) and road resource cost (cents/km) based on travel distance, capacity, road wear and tear, pavement wear and bridge wear. The study is conducted using a vehicle performance and fuel consumption model developed jointly by the Department of Mechanical and Manufacturing Engineering at the University of Melbourne and the SAE-Australasia. Fuel consumption is estimated for rigid and articulated trucks and road trains operating at three selected masses (tare, average and fully laden) over typical urban and highway drive cycles. The results obtained show good correlation between fuel consumption and road resource cost on the basis of which a scenario is identified for recovery of fully allocated road expenditure through fuel-only charges. Sensitivity analysis of the effect of factors such as engine power, vehicle age and the use of fuel saving technologies on the proposed charges is also presented.

## INTRODUCTION

Australia is a vast country/continent divided into six states and two territories. The overwhelming majority of the population is concentrated along the south and south-eastern coast and the inland regions are thinly populated. The country is serviced by a road network comprising some 810,000 km (1 km=0.621 mile) of sealed and unsealed roads. According to Austroads [1], almost A\$5.8 billion was invested in Australian roads in 1990-91 and road freight accounted for about 70% of tonnes and 34% (20% in 1971) of tonne-kilometres carried of the total transport freight. The responsibilities for maintaining and improving the Australian road network lies with the Federal Government (National Highway System) and State and Local Governments (State Highways, Arterial and Local Roads).

The management of the road network (States and Territories) is responsible for raising revenue from road users. This revenue, not all of which is used for road

maintenance, is raised by a mechanism including some or all of the following means:

-Registration fees: a flat fee designed to cover maintenance of the vehicle register and safety research in addition to a variable component based on the tare mass of the vehicle and designated for roadwork;

-Road tolls ;

-Occasional fuel taxes;

-State fuel franchise fees: these fees are applied to the sale of petrol and automotive diesel fuel in all States and Territories with the exception of Queensland. LPG is subject to franchise fees only in Tasmania. The franchise license fees are based on a percentage of the wholesale price and the volume of fuel sold in the month to which licence is applied. The equivalent rates applicable for January 1993 ranged from 5.28 to 6.86 cents/litre ((1 A\$≈0.74 US\$, 1 litre=0.264 US gallon). Generally, diesel fuel consumed off-road is exempted or eligible for full rebates;

-Federal contribution from fuel excise: Federal excise fuel duty has been applied to road transport fuel refined in Australia since 1929. Funds raised from fuel excise have been used to fund state roads since 1931. Diesel and petrol excises have been levied at the same rates since 1973. The rate as in February 1993 was set at 26.2 cents/litre and is indexed using the Consumer Price Index twice a year. Some off-road users of diesel fuel (but not petrol) are eligible for partial or full rebate of the excise.

This charging mechanism is difficult and inefficient to manage and is inequitable. For example, the use of the tare mass as a basis for the roadwork charge does not take into account the fact that gross mass varies within a much greater range than tare mass and axle load is a critical factor in road tear and wear. Another parameter that contributes greatly to both road resource cost and road system capacity is the annual vehicle travel (vehicles which travel far per year contribute more to road wear and tear and to the need for increased system capacity) which is also ignored by the current charging systems.

In an effort to reform Australia's road transport system, the National Road Transport Commission (NRTC) was established in early 1992 with the responsibility of developing nationally uniform transport legislation aimed at improving road safety and transport efficiency. The three

areas covered by the NRTC's brief were charges for heavy vehicles, technical standards for heavy vehicles and vehicle operation and registration of heavy vehicles and licensing their drivers [2]. The main principle on which transport reform was to be based was to ensure that the funds required to operate and manage the road network and vehicle operations in general should be raised equitably. It was deemed that equity is essential to economic efficiency for the country as a whole since unrealistic charges for road costs may introduce distortion in the demand and supply in the transport sector and hamper the efforts to improve the overall efficiency of the Australian economy. A balance was to be maintained between the pitfalls of low charges for road use causing excessive demand for roads and high maintenance costs and subsidy of road transport at the expense of the other modes of freight transport such as railway and sea.

It is widely accepted that any road cost recovery system that is aimed at improving road transport efficiency should satisfy the following criteria:

- Nationally uniform charging system;
- Efficient collection mechanism;
- Flexibility to adapt to any changes in road cost;
- Total road cost recovery through the system;
- Contributions from each type of road users is proportional to the damage it causes;
- Road expenditure not attributable directly to road users (eg, environmental effects) should be distributed across all road users.

The charging system adopted by the NRTC envisages the full road cost recovery by July 1, 1995 based on average distance travelled for rigid and articulated trucks. For road trains full road cost recovery is envisaged by July 1, 2000 [2]. This system comprises a fixed annual charge ranging between \$300 and \$8500 (access charge and mass-distance charge) and road use charge of 18 cents/litre taken from the federal diesel excise tax.

The current study is an extension of a previous work done by the University of Melbourne for the Road and Traffic Authority of New South Wales [3] and by the NRTC.

## METHODOLOGY

## THE SIMULATION MODEL

The computer model used (TABESAM) was jointly developed by the University of Melbourne and the SAE-A in the late eighties [4] and has been successfully used since in a number of projects. The model is capable of simulating a range of real driving cycles, such as the rigid vehicle driving cycle or the urban and highway articulated vehicle driving cycles, with speed time records for every second duration. Fuel maps of steady-state engine tests are used to predict dynamic operation, ie during transients the engine is assumed to behave as though it were under steady conditions with respect to fuel consumption rate as a function of power and speed. Simple concepts of gear shifting are applied to describe transmission shifts and the duration of gear shifting is a constant selectable value (normally one second). Driveline efficiency is assumed constant over the whole driving cycle irrespective of gear selection, torque transmitted and propeller shaft speed. Cross-winds are assumed to exert a known effect on the drag coefficient and environmental conditions remain constant during a simulation run.

The cycle files contain the driving data, with a speed data point (km/h) at every one second interval. The Fuel map files contain the steady-state power versus engine speed, with fuel consumption rates (kg/h) cross tabulated. The model, as it tries to follow the driving cycle as close as possible, calculates the forces imposed on the vehicle, the engine speed and the power demand and then refers to the fuel map for fuel consumption rates.

## THE VEHICLES

The vehicles considered include four types of articulated trucks and four types of rigid trucks (Table 1). The vehicle parameters required to simulate the operation of the different types of trucks (vehicle types A to H) such as engine power, rolling resistance coefficient ( $C_r$ ), frontal area and aerodynamic drag coefficient ( $C_d$ ) were taken within the ranges identified for ten types of vehicles by an ARRB study [5].

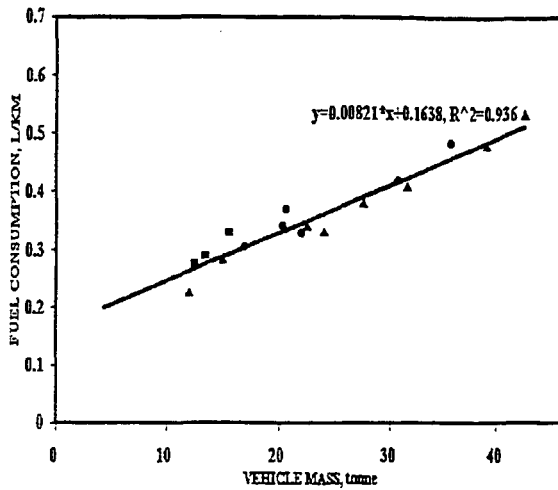
Vehicle masses (laden, average and tare) and configuration of the eight types of trucks was also supplied by the NSW RTA. Average vehicle masses based on 1985 SMVU (Survey of Motor Vehicle Use) data were also used.

Table 1. Trucks powered by diesel engines

Vehicle Type & Configuration	Vehicle Mass. tonne		
	Laden	Average	Tare
Artic			
(A) 6-axle (O O O O O O)*	42.5	32.0 (35.6)**	15.5
(B) 5-axle (O O O O O)	39.0	26.0 (30.7)	13.5
(C) 4-axle (O O O O)	31.5	20.6 (24.0)	12.5
(D) 3-axle (O O O)	24.0	16.1 (22.0)	10.5
Rigid			
(E) 4-axle (O O O O)	27.5	18.3 (20.3)	10.5
(F) 3-axle (O O O)	22.5	15.1 (16.9)	8.9
(G) 2-axle (O O)	15.0	9.9 (9.0)	6.8
(H) 2-axle (O O)	12.0	6.7 (6.5)	4.3

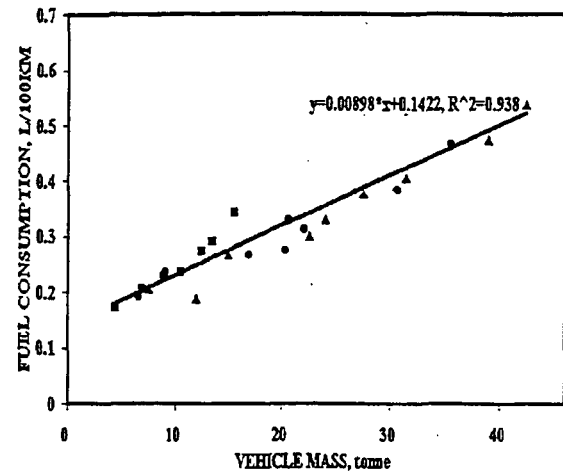
\* Denotes approximate axle location

\*\* Values in parentheses are ABS-based average masses



▲ LADEN MASS/DIESEL ● AVERAGE MASS/DIESEL ■ TARE MASS/DIESEL

Figure 1. Fuel consumption as a function of vehicle mass (urban cycle)



▲ LADEN MASS/DIESEL ● AVERAGE MASS/DIESEL ■ TARE MASS/DIESEL

Figure 2. Fuel consumption as a function of vehicle mass (highway cycle)

### ROAD RESOURCE COST PARAMETERS

There is a wide variety of pavement damage (or deficiencies) that are attributable to traffic and interaction of the climate with traffic loads, and the prime cause of each type of pavement damage is controversial when it comes to the allocation of road resource cost parameters. Road resource cost parameters used in this study, reflecting road usage, are vehicle kilometre travel (vkt), capacity represented by the product of passenger car units and travel distance (PCU.km), road wear and tear represented by the product of equivalent standard axles and travel distance (ESA.km), pavement wear represented by the product of vehicle mass and distance travelled (tonne.km), road construction represented by the product of the fourth root of ESA and the distance travelled (ESAI.km) and bridge wear (tonne.km). The effects of congestion (PCU), accidents, noise and air pollution on road resource cost are not included in the determination of charges. The costs per unit parameter are based on all travel in the State of NSW and were supplied by NSW Road and traffic Authority. Passenger Car Unit (PCU) values (Table 2) were taken from a report prepared by the NSW Taskforce on Road User Charges. ESAs were calculated from an equation developed on the basis of the method recommended by NAASRA [6].

On the basis of the costs allocated to the different road usage parameters from the gross revenue that is to be raised from road users coupled with the vehicle fleet characteristics, unit parameter costs can be determined as shown in Table 3. Load-equivalence factors, used for designing and analysing pavements and assessing the damage caused by traffic, are based on axle type (single, tandem or triaxle) and load per axle. Other vehicle parameters such as tyre pressure tyre type (single, dual or

super singles), suspension system (none, leaf, air etc.) and axle spacing, believed to affect pavement wear, are not taken into account in this study.

Table 2. PCU values for different vehicle classes

Vehicle Class	PCU
Motorcycles	0.5
Passenger Cars	1.0
Light Commercials	1.0
Light Trailers GVM 4.5 tonne	1.0
Prime Movers	1.0
Light trucks (4.5-12 tonne)	2.0
Heavy Trucks (rigid 12 tonne and over)	2.0
Rigid buses	2.0
Heavy Trailers	2.0
Articulated Trucks and Buses	3.0

Equivalent Standard Axles (ESA) were calculated for the vehicle types under consideration on the basis of the method proposed by NAASRA [6] in which the standard axle is defined as a single axle with dual wheels that carries a load of 8.2 tonne (18 000 lb in the USA [7], 13 tonne in the OECD [8]). Loads on other axle configurations that cause the same damage as the standard axle are shown in Table 4. For a vehicle having  $n$  axle groups the ESA value will be equal to the sum of all individual groups [7] (EQ 1), where  $P$  is the load on each axle group in tonnes and the values of  $C_j$  are given in Table 4.

$$ESA = 2.2118 \times 10^{-4} \sum_1^n \left( \frac{P}{C_j} \right)^4 \quad (1)$$

Table 3. Costs per unit allocation parameter for all travel in NSW (1992)

Travel	0.077 cents/vkt
Capacity	0.530 cents/PCU.km
Road Wear and Tear	1.838 cents/ESA.km
Pavement Wear	0.017 cents/tonne.km (tonnes gross mass, all vehicles)
Road Construction	2.666 cents/ESAI.km (ESAI represents the 4th root of the vehicle's assigned ESA rating)
Bridge Wear	0.015 cents/tonne.km (tonnes gross mass, vehicles with gross mass exceeding 12 tonne)

## THE RESULTS

### RESOURCE COST

Resource cost (RC) in cents per vehicle kilometre travel can be calculated from the following equations:

Trucks with GVM exceeding 12 tonne

$$RC = 0.077 + 0.53PCU + 1.838ESA + 0.017GVM + 2.666ESAI + 0.015GVM \quad (2)$$

Trucks with GVM less than 12 tonne

$$RC = 0.077 + 0.53PCU + 1.838ESA + 0.017GVM + 2.666ESAI \quad (3)$$

Fuel consumption data obtained from simulations using TABESAM for all vehicle types and masses indicate linear relationships with mass for both urban and highway driving cycles (Figures 1 and 2).

### CORRELATION BETWEEN ROAD RESOURCE COST AND FUEL CONSUMPTION

The correlation between fuel consumption (litre/km) and road resource cost (RC, cents/km) for all masses and for urban and highway driving cycles are shown in Figure 3. The results are for laden (maximum load), tare (zero load) and two average masses based on RTA-averages and ABS-averages (Fiche 27, Table 69 in ref. [9]) in both urban and highway operations. Compared with the average masses supplied by the RTA, ABS average masses are significantly higher for cases A, B, C and D, moderately higher for cases E and F and slightly lower for cases G and H (Table 1).

The relationships between fuel consumption and RC for trucks in both urban and highway operation can be approximated by the straight lines as follows:

$$(RC) = 37.6 \times (FC) \quad \text{Laden} \quad (4)$$

$$(RC) = 19.6 \times (FC) \quad \text{RTA Average} \quad (5)$$

$$(RC) = 23.8 \times (FC) \quad \text{ABS Average} \quad (6)$$

$$(RC) = 13.3 \times (FC) \quad \text{Tare} \quad (7)$$

The correlation coefficients for ABS averages are relatively low due to the sensitivity of ESAs to vehicle mass increases, particularly for case D in which ESA increased from 0.893 (vehicle mass 16.1 tonne) to 3.123 (vehicle mass 22.0 tonne). If we assume that the average mass for the latter case is 19.0 tonne instead of 22.0 tonne (by reducing tare mass and/or average load carried by 3.0 tonne), the correlation coefficients increase to 0.823 for urban conditions and 0.815 for highway conditions and EQ 6, for example, becomes

$$(RC) = 22.6 \times (FC) \quad (8)$$

Assuming that actual average masses lie somewhere between RTA averages and ABS averages, the fuel-based resource cost charge (defined as the ratio of resource cost RC in cents/km and fuel consumption in litres/km) can be set in the range 19.0-24.0 cents/litre.

The regression lines for all the masses considered are also shown in Figure 3 by the solid lines. It is apparent that ABS averages lie closer to the line mid-point between laden and unladen cases whereas RTA averages are closer to the tare line.

### CHARGING SCHEDULE

The estimated charging schedule based on these RC ranges and average annual distances travelled is shown in Table 5. Shown also in this table are the charges proposed by the NRTC on the basis of the same annual distances travelled. The NRTC charge is made up of two components: a fixed annual charge (column 5) and a fuel charge (column 6) based on a running charge of 18 cents /litre [10]. The total NRTC charges shown in column 7 also indicate the amount of under-recovery and over-recovery for each class of vehicles estimated on the assumption of full allocated expenditure recovery for that class. If these deviations are taken into account (by subtracting the bracketed values from the total charge algebraically in column 7), the maximum fuel-only charges (24 cents/litre) would be less than the NRTC charges by 4.3 to 42.1% (column 8). The NRTC estimates that a fuel-only charge of 25.3 cents/litre can raise equivalent revenues to the NRTC charges. The reason

Table 4. Axle loads which cause equivalent damage and equivalence load constants ( $C_j = P_j/80.44$ )

Axle	Single	Single	Tandem	Triaxle
Tyre Config.	Single	Dual	Dual	Dual
Load, $P_j$ (kN)	53	80.44	135	181
$C_j$	0.659	1.000	1.678	2.250

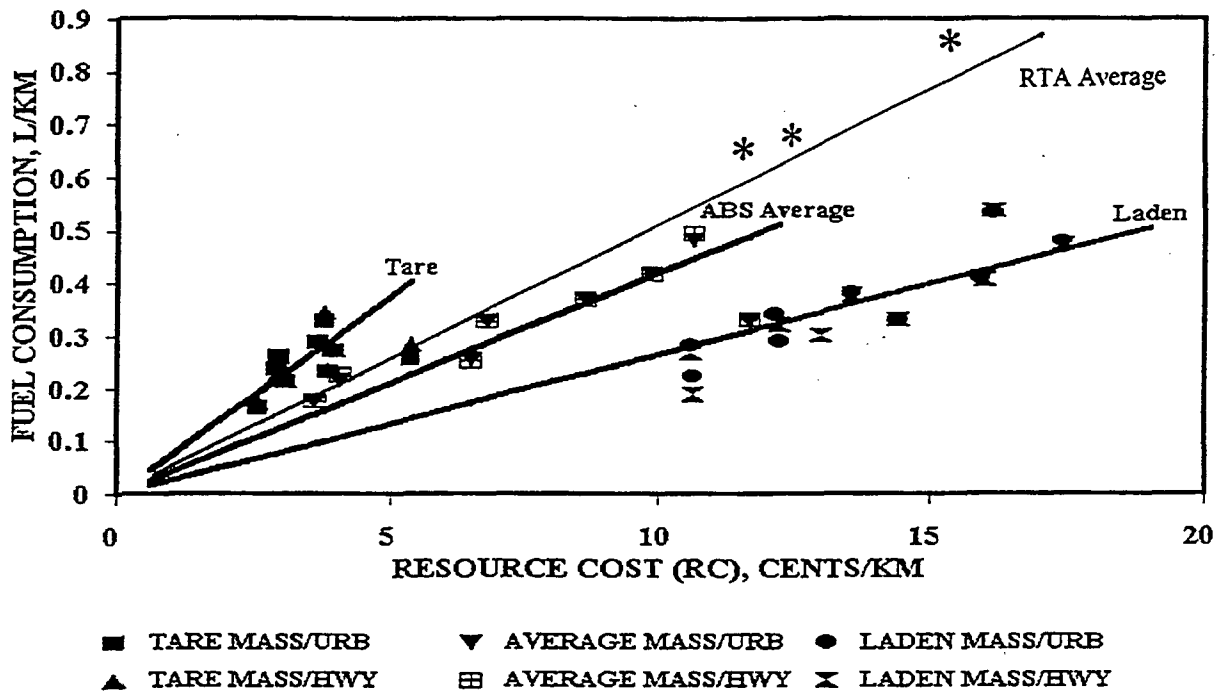


Figure 3. Correlation between road resource cost and fuel consumption

Table 5. Estimated charging schedule

Vehicle	GVM (tonne)	Travel (km pa)	Fuel-Only		NRTC Charges		Δ %
			Charge (\$ pa)	Fixed (\$ pa)	Fuel (18 c/l) (\$ pa)	Total (\$) (\$ pa)	
<i>Artic</i>							
A	42.5	116,670	10,860-14,190	4,000	11,667	15,667(-1,115)*	-15.4
B	39.0	49,494	3,942-5,125	3,750	4,405	8,155(+2,194)	-14.0
C	31.5	45,967	3,942-4,260	1,300	3,631	4,931(+216)	-11.0
D	24.0	23,887	1,547-1,985	1,050	1,696	2,746(+671)	-4.3
<i>Rigid</i>							
E	27.5	62,750	3,987-5,126	2,000	4,769	6,769(+1,179)	-8.3
F	22.5	32,726	1,547-2,063	800	2,389	3,189(+500)	-23.3
G	15.0	25,426	1,065-1,405	500	1,373	1,873(+301)	-10.7
H**	12.0	16,680	281-369	300	767	1,067(+430)	-42.1

\* Values in brackets indicate under-recovery (-) or over-recovery (+) for fully allocated expenditure

\*\* All drive axles are double-tyre except for this configuration

for the under-recovery associated with the charges estimated in this study is probably due to an under-estimation of the average vehicle masses and/or low unit allocation parameter costs.

Higher RC values are associated with the heavier vehicles which in their turn show a greater range of variation of fuel consumption between operations fully laden and unladen. This is obviously due to the big difference between GVM and tare mass for articulated trucks and to the linear relationship between fuel consumption and vehicle mass (Figures 1 and 2).

#### SENSITIVITY ANALYSIS

**Effect of Drive Mission:** Fuel consumption for trucks and buses and for the engines selected for each type does not vary appreciably with urban and highway driving conditions as evident from Figures 1 and 2. Hence driving mission does not seem to have a significant effect on fuel-based road charges.

**Effect of Vehicle Mass:** The term vehicle mass here refers to the three mass classes that are designated laden (maximum mass), average (partially laden vehicle) and tare

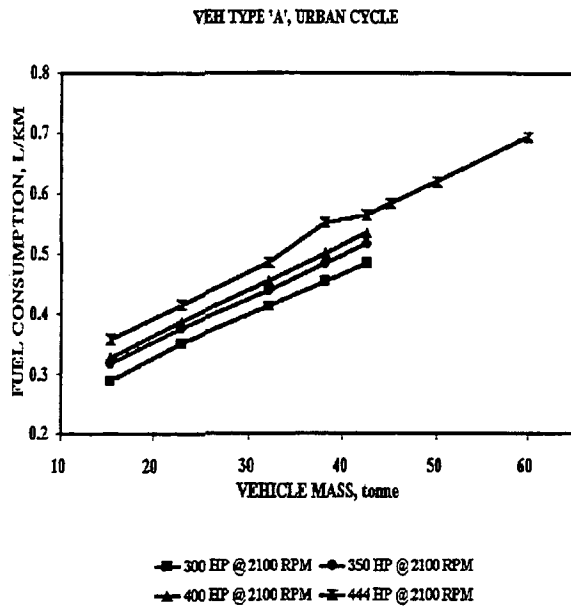


Figure 4. Effect of vehicle mass on fuel consumption (urb)

(unladen vehicle). Figure 3 readily shows that the straight lines representing fuel consumption as a function of road resource cost for the three representative masses assumed for each vehicle class diverge starting from a common zero origin. The estimated fuel consumption for vehicle type A varies between about 0.32 litre/km unladen and 0.54 litre/km fully laden. The corresponding values of road resource cost range between about 4.6 cents/km for tare mass to about 20.0 cents/km for maximum mass. This indicates that approximately 63% increase in fuel consumption is accompanied by about 330% increase in road resource cost. If ABS average masses are taken as the basis for the calculation of resource cost (EQ 6) the above mentioned 63% increase in fuel consumption will be accompanied by a 63% increase in resource cost. Simulation results for type A truck show that fuel consumption generally varies almost linearly with gross vehicle mass at constant engine power which indicates a linear relationship between road resource cost and vehicle mass in both urban and highway operation (Figures 4 and 5).

**Effect of Engine Power:** Simulation runs were also made for trucks with engines representing the upper (high power) and lower (low power) limits of the power ranges specified in [5]. The engines used ranged in power output between 150 HP @ 2600 RPM to 444 HP @ 2100 RPM. The fuel consumption results of the simulations using high and low power engines are shown in Table 7. In highway operation fuel consumption increases by up to 7% for vehicle type A and 40% for vehicle type H when engine power increases from the lower to the upper limit. In urban operation the increases are respectively 9% and 17%. The effect of engine power in the cases of vehicle types D, F, and G is not clear-cut and higher engine power sometimes shows lower fuel consumption. This can be attributed to the characteristics of the engine selected for a particular vehicle type and the other vehicle parameters such as drag coefficient, rolling

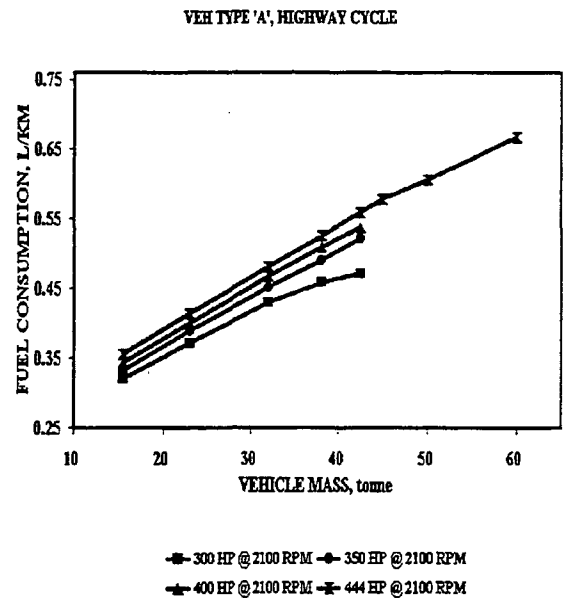


Figure 5. Effect of vehicle mass on fuel consumption (hwy)

resistance coefficient and frontal area. Generally, increasing engine power with all other parameters remaining unchanged will lead to a steady increase in fuel consumption. This can be explained as follows. The rate of fuel consumption for any engine is given by

$$\text{Fuel Rate} = \text{Const} \times \text{Swept Vol} \times \text{Air Density} \times \text{RPM kg/h}$$

Engine power output can be increased by increasing the swept volume, inlet air density (turbocharging) or engine speed. As an illustration let us consider Cummins engines NTC 300, 350, 400 and 444 all @ 2100 rpm. A 42.5 tonne truck with a 300 HP @ 2100 rpm engine will not make the highway cycle and will operate at maximum engine power and speed. With a 350 HP @ 2100 engine the truck will just make the cycle and also operate at maximum engine power and speed. With a 400 HP or 444 HP @ 2100 rpm engines the truck will easily make the cycle and operate at 350 HP @ 2100 rpm. Comparison of fuel consumption rates of these engines at these conditions shows that fuel consumption rate increases with increased engine rated power as shown in Table 6.

Applying resource cost charges based on either equation 5 or 6 to two identical trucks of equal GVM with different engines will lead to the operator of the vehicle with higher engine power paying more for road damage despite the fact that engine power has nothing to do with road damage. If

Table 6. Increase of fuel consumption with engine power

Engine Type	Speed rpm	Oper Power kW (HP)	Fuel Rate kg/h
NTC-300	2100	224 (300)	44.2
NTC-350	2100	261 (350)	53.8
NTC-400	2100	261 (350)	54.3
NTC 444	2100	261 (350)	56.8

Table 7. Fuel consumption for different engine powers and fully laden vehicle mass, highway and urban cycles

Veh Type	Urban Cycle			Highway Cycle		
	Fuel Consumption, litre/km			Fuel Consumption, litre/km		
	high	inter	low	high	inter	low
(A)	0.5629	0.5336	0.5156	0.5603	0.5383	0.5232
(B)	0.4977	0.4803	0.4504	0.4903	0.4749	0.4471
(C)	0.4246	0.4089	0.3837	0.4181	0.4065	0.3879
(D)	0.3545	0.3297	0.3550	0.3456	0.3317	0.3495
(E)	0.3957	0.3801	0.3550	0.3896	0.3786	0.3647
(F)	0.3191	0.3410	0.3428	0.3202	0.3021	0.3489
(G)	0.2627	0.2834	0.2794	0.2677	0.2679	0.2371
(H)	0.2372	0.2242	0.2035	0.2463	0.1896	0.1750

Table 8. Sensitivity analysis (% change) of urban and highway fuel consumption relative to basic vehicle configuration (laden mass and Intermediate engine power)

Veh Type	% Change									
	Low Power		High Power		New Engine		Average Mass		Tare Mass	
	urb	hwy	urb	hwy	urb	hwy	urb	hwy	urb	hwy
(A)	-3.4	-2.8	+5.5	+4.1	—	—	-14.8	-13.2	-38.6	-36.1
(B)	-7.3	-5.8	+3.6	+3.2	-8.5	-4.8	-20.4	-19.1	-40.0	-38.5
(C)	-6.2	-4.6	+3.8	+2.8	-6.4	+0.4	-19.0	-18.8	-33.1	-32.6
(D)	-2.5	+5.3	+7.5	+4.2	-12.2	-3.9	-17.9	-17.0	-29.6	-28.6
(E)	-6.6	-3.7	+4.1	+2.9	-6.5	0.0	-17.0	-17.1	-31.4	-31.1
(F)	+0.5	+15.5	-6.4	+6.0	-4.3	+7.9	-16.6	-11.5	-30.3	-24.1
(G)	-1.4	-11.5	-7.3	0.0	-5.6	-8.8	-13.5	-11.6	-24.3	-19.9
(H)	-9.2	-7.7	+5.8	+29.9	-10.2	+13.3	-18.9	+1.4	-26.9	-8.5

+ increase in fuel consumption relative to base values

- decrease in fuel consumption relative to base values

we take vehicle type B fully laden with a 400 HP engine with highway fuel consumption of 0.498 litre/km, the calculated resource cost will be 12.2 cents/km. Resource cost based on fuel consumption for the same vehicle and operating conditions with a 300 HP engine (fuel consumption 0.45 litre/km) will be equal to 11.0 cents/km. This means that the first operator will be charged about 11% more for road resource cost simply because his truck is powered by an engine with higher output.

**Effect of Vehicle Age:** It is assumed in this study that vehicle age is determined by engine age. The fuel maps used in the simulations are dated between 1981 and 1986. This means that some of the engines used are already technically obsolete and others are on their way to becoming obsolete. Several fuel maps for engines designed for the nineties are available in TABESAM's data bank and were used in the simulations to assess the effect of using advanced and fuel efficient engines on fuel consumption in trucks. New engines generally demonstrate better fuel economy than the base engines, particularly in urban driving. This means that trucks with fuel efficient engines will incur lower charges for resource costs (based on fuel consumption) than trucks with relatively inefficient engines despite the fact that the damage to road pavement might be the same in both cases assuming equal GVM.

**Effect of fuel saving technologies:** A previous study [11] using TABESAM showed that fuel consumption can be reduced appreciably in articulated trucks by lowering the governed engine speed, say from 2100 to 1900 RPM (5%), changing over from standard radial to wide-base radial tyres (7%) and reducing aerodynamic drag (air shield: 5%, fully integrated aerodynamic device: 10%). Fuel only charging system can therefore disadvantage modern trucks which are equipped with state of the art devices for maximum fuel economy.

**The Total Picture:** The individual effect of any of the parameters mentioned above is reflected in the sensitivity of fuel consumption to the variation of these parameters. This sensitivity is summarised in Table 8 which shows the percentage change in fuel consumption and its sign for both urban and highway operation when type of engine, engine power and vehicle mass are changed. The changes presented are relative to vehicles of maximum mass (fully laden) and intermediate engine power used as base engines. The changes are generally as expected and can be summarised as follows:

-Lower engine power results in lower fuel consumption. Regression analysis shows that the reduction in fuel consumption is almost the same for urban and highway operations;

Table 9. Vehicle parameters and RC for road trains

Vehicle	Average Mass	ESA	PCU	FC	RC
	tonne				
B Double (8-axle)	44	2.7	3	63	11.45
Double Road Train	58	3	3	65	12.54
Triple Road Train	84	3.9	3	86	15.27

-Higher engine power generally results in increased fuel consumption;

-New engines are generally more efficient and give better fuel consumption results particularly in urban operation;

-When vehicles are operated at masses below their GVM fuel consumption can decrease by up to 40% in some cases.

#### ROAD TRAINS

Detailed data on road train parameters were unavailable during the study; therefore, TABESAM could not be used to predict the fuel consumption for these vehicles. Table 9 shows the average parameters for three examples of this class of vehicles taken from reference [10] and the calculated RC values. The three points representing these vehicles are indicated by the star markings in Figure 3 and lie close to the regression line for the RTA average masses. The fuel-only charging rate proposed in this study will therefore be lower than the charges proposed by the NRTC.

#### CONCLUSIONS

The conclusions to be drawn from the present study are the following:

- 1) Road resource cost charges based on fuel consumption demonstrate better flexibility by taking into account the operation of vehicles at different masses. This makes it more equitable to vehicles that operate partially laden or operate fully laden only part of the time.
- 2) Resource cost values based on maximum laden masses indicate that operators will pay charges that are higher than the actual damage they cause when almost all operations are carried out with less than a full load. Deliveries such as liquids and foodstuffs result in load factors less than half. Similarly, much interstate traffic is volume rather than mass limited. To overcome this problem, it might be necessary to base resource cost on average vehicle masses instead of maximum masses.
- 3) On the basis of the costs per unit allocation parameter provided for this study and fuel consumption estimates, the fuel-only charge could be set between 19.0 to 24 cents/litre for trucks (GVM 12 tonne and over). However, the upper limit seems to be more appropriate since it is only marginally lower than what is required (25.3 cents/litre) nationally for full road resource cost recovery.
- 4) The main advantages of fuel-only charging system is improved equity by directly linking the imposed charge with actual road use (pay-as-you-go) without the need for large up-front fixed charges and simplified collection mechanism.
- 5) Collection can be effected through the Federal excise tax by oil companies with no extra cost to operators. Funds for

road management can then be transferred to States and Territories.

6) The method of charging for road resource cost on the basis of fuel consumption can be used, if adopted nationally, to account for interstate travel and compensate for damage done to the roads by vehicles registered in other states.

7) There is the possibility of road cost recovery levy avoidance through various existing concession systems. On the basis of this a more detailed investigation of how state and federal government departments could assist in levy avoidance is warranted.

8) Further work is required to improve the precision of the proposed charging system, by accounting for -costs attributable to accidents, pollution and noise -the effect of improved vehicle technology and advent of alternative fuels.

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