ARFCOM, SPEED PROFILES AND FUEL CONSUMPTION: RESULTS FROM A CONGESTED ROAD IN JAVA

By

John L. Hine
Transport Research Laboratory, UK

Harlan Pangihutan Sinaga
Institute for Road Engineering, Bandung

International Division
Transport Research Laboratory
Crowthorne
Berks
RG45 7JQ
UK

Tel: +44 1344 773131
Email: jhine@trl.co.uk

ARFCOM, SPEED PROFILES AND FUEL CONSUMPTION: RESULTS FROM A CONGESTED ROAD IN JAVA

ABSTRACT

Road investment appraisal models have had difficulty incorporating the effects of congestion on vehicle fuel consumption. The new Highway Development and Management Model, HDM-4, incorporates the Australian Road Research Board's Model "ARFCOM" to predict fuel consumption in combination with a simulated vehicle speed profile. A key determinant of the simulated speed profile is acceleration noise (the standard deviation of the second-by-second acceleration) which is in turn derived from the highway volume capacity ratio. To investigate this further, detailed speed profiles were obtained for a light passenger vehicle (a Toyota Kijang) and a medium truck on a 17 km congested road close to Bandung in Java. In total 100,000 speeds and 10,000 fuel readings were measured over 1000 km of test runs. Speed data were compared with predictions of the Indonesian Highway Capacity Manual (IHCM) and observed fuel consumption data were compared with ARFCOM's predictions. It was found that the IHCM model appeared to overestimate the Kijang's speed although a close estimate of the truck's speed was obtained. Total observed fuel consumption was found to be three per cent more for the truck and six per cent more for the Kijang compared with ARFCOM's predictions. The data were analysed in 30 second and four minute intervals and it was found that multiple regression models were able to give good explanations of the IHCM predicted speeds and of the ARFCOM's predicted fuel consumption. However only a very poor explanation of acceleration noise was found from formulae based on the highway volume capacity ratio. In view of the promising results it is proposed that relatively simple multiple regression models be used to predict fuel consumption under congestion.

1. INTRODUCTION

Many studies have been carried out to determine the fuel consumption of vehicles whilst travelling at near constant speeds, or at speeds unaffected by traffic congestion. The results of these studies have been incorporated into road planning models such as the Transport Research Laboratory's Road Transport Investment Model (RTIM3), the World Bank's Highway Design and Maintenance Standards Model (HDM III) and road maintenance programs such as the Indonesian Integrated Road Management Systems (IRMS). In contrast much less is known about how to model fuel consumption with variations in speed brought about by traffic congestion.

In Indonesia and in many other countries there is pressure to increase the capacity of existing roads and provide new roads in order to reduce the effects of interurban traffic congestion. An important component of the benefits of new road investment relates to predicted reduction in fuel consumption. It is for this reason that realistic and effective models of fuel consumption should be used within highway planning models. However, until now, the planning models have been limited because the fuel consumption component has ignored the effects of congestion.

The Australian Road Research Board's Model "ARFCOM" (see Biggs, 1988) provides a useful approach to the modelling of fuel under varying speed. The model can calculate fuel consumption, from a second-by-second speed profile input by the user. The approach is, perhaps, of most use for urban traffic modelling applications where the detailed modelling of traffic movements has been achieved. Far less is known about the speed profiles of interurban traffic movements in developing countries.

In order to incorporate the effects of congestion on fuel consumption within the new road investment planning model the Highway Development and Management Model, HDM-4, it has been proposed by Greenwood and Bennett (1995,1996) and Bennett (1996) that speed fluctuation data derived from a "Monte Carlo" simulation be incorporated into the ARFCOM model's fuel consumption equations. The standard deviation of speed accelerations "acceleration noise" is the key parameter that governs the speed profile within the simulation. Acceleration noise is made up from a number of components; the most important is traffic noise which is dependent upon the volume capacity ratio of the road. As the volume capacity of the road increases so traffic noise increases and, as a result, there is an increase in speed fluctuations.

In this study fuel consumption and speed profile data have been collected from a light passenger vehicle (a Toyota Kijang) and medium truck running on a 16.7 km congested interurban road near Bandung. Road alignment, road width and traffic data were also collected for the study. The speed profile data were fed into the ARFCOM model and the results compared with the fuel consumption observations. The speed data were compared with predictions from the Indonesian Highway Capacity Manual.

In total, 100,000 speed observations and 10,000 fuel consumption observations were recorded. The data were aggregated into two analysis periods (30 seconds and four minutes) and analysed by multiple regression analysis.

2. INSTRUMENTATION & DATA COLLECTION

The following data were collected for the study: speed profiles, fuel consumption, road geometry, road width, traffic volumes, and roadside traffic friction. The data were analysed using ARFCOM, basic and spreadsheet computer programmes.

Speed profile data were collected from a sensor fitted to the odometer cable. The data were recorded in one second intervals and stored in a Grant '1000 Series' Squirrel Logger.

Fuel consumption data were collected using an Ono Sokki FP-2140H flow detection meter coupled with an Ono Sokki LC-5100 System paper recorder. For the medium truck (a two axle, 190 HP, Mitsubishi FUSO) a small extra fuel tank (an Ono Sokki MF-035) was fitted to take the return line from the diesel engine. The fuel meter was then placed between the fuel tank and the MF-035. Thus the meter recorded only the net outflow from the main fuel tank. Fuel consumption data was recorded every ten seconds on a paper roll.

Data relating to the gradient and curvature of the test road were collected using a vehicle fitted with the Australian Road Research Board's Road Geometry Data Acquisition System (RGDAS).

The principal data collection surveys were carried out on the main road between Cileunyi and Nagreg, South East of Bandung, within the Bandung valley. The road has a high traffic volume (a mean of around 2000 passenger car equivalents (pce) per hour were observed) with higher volumes towards Cileunyi and Bandung. The total test section length was 16.7 km, of this 3.7 km were dual carriageway. Three quarters of the road is in flat-to-rolling terrain but in the last quarter the road rises 140 metres. Most of the road is relatively built up although heavy congestion appears to be concentrated at the Majalaya road junction and at the town of Cicalengka. Road works were being undertaken at two places along the road; for most of the time these did not appear to add significantly to traffic congestion.

Road widths and roadside traffic friction along the test section were estimated by eye. Using the photographs in the Indonesian Highway Capacity Manual as a rough guide, traffic friction was estimated on a scale of one to four.

After the road alignment had been surveyed, the main surveys were undertaken. In June 1997 the instrumented Kijang carried out 28 runs on the test section over a period of four days. In September 1997 the instrumented truck undertook 34 runs on the test section over a period of three days. For the truck, different loads were used on the different days. The gross vehicle weights were 13.4, 12.2, and 9.95 tonnes respectively for days 1, 2 and 3. All runs were carried out in daylight during the morning and early afternoon. At the time of the test runs traffic surveys were undertaken at three points along the road. To test fuel consumption at constant speeds, additional runs were also undertaken at a range of different speeds on one of the toll roads next to Bandung.

3. VEHICLE SPEEDS

The data from the surveys were combined together into 30 second analysis periods. The resulting speed distributions are shown in Figures 1 and 2. As can be seen a wide range of speeds were observed. For both vehicles the modal observation occurred at 35 to 40 kph. However average running speed was found to be lower for the Kijang than for the truck. This probably reflects the differences in the pattern flows and the related congestion on the survey days.

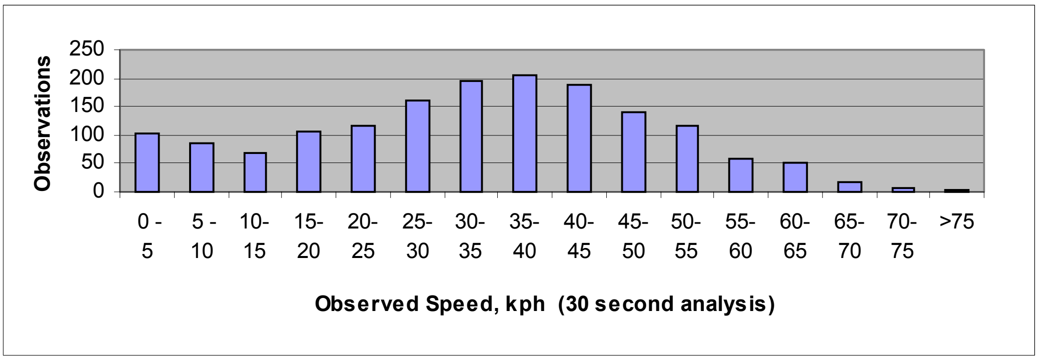

Figure 1. Speed Distribution for Kijang light vehicle

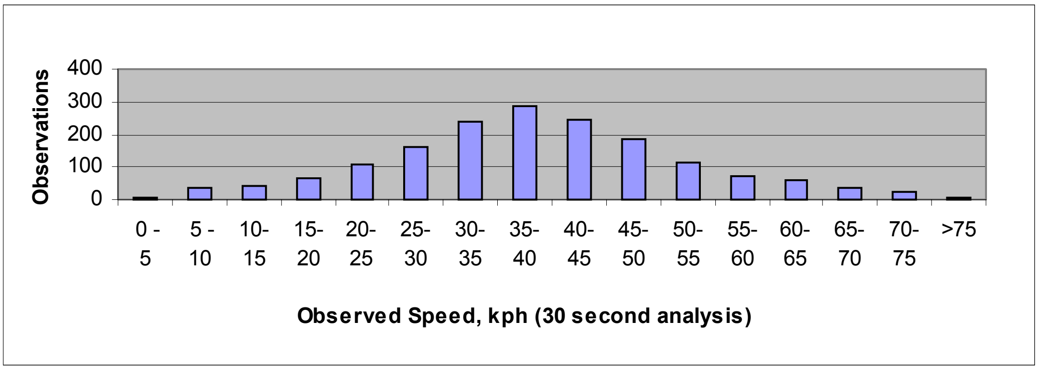

Figure 2. Speed Distribution for Medium Truck

Both for the speed and fuel consumption the main method of data analysis was to combine data together into 30 second intervals. As far as possible, the speed and fuel data were related to the associated road gradient, width and traffic data that were derived from the other surveys. For each run the traffic data was allocated into five sections along the length of the road. The second and fourth traffic estimates were interpolated from the three traffic stations' data. Excluding observations when vehicles were at rest or travelling less than 5 km/h, a range of data relating to speed, fuel and road condition, are presented in Table 1 relating to the 30 second interval periods.

Table 1. Variables used in the statistical analysis. (Data relates to 30 second analysis period, omitting observations when speed drops below 5 kph)

	Key	Units	Kijang Light vehicle Mean	St. Dev.	Truck Mean	St. Dev.
Observed mean speed	V	Kph	34.7	14.7	38.8	13.67
Acceleration	ACC	m / sec^2	0.0058	0.151	0.006	0.15
Acceleration Noise	ACCN	m/ sec^2	0.45	0.146	0.416	0.123
Rise	RISE	m / km	9.22	14.1	8.807	13.2
Fall	FALL	m / km	-7.59	12	-8.12	12.2
Curvature	CURV	deg / km	81.5	78.7	80.7	75.8
Road width	RW	m	9.15	4.68	9.15	4.67
Roadside Friction Index	RFI	scale: 1-4	2.04	0.746	2.04	0.75
Traffic	TRAF	pce / hr	1996	377.5	2025	467
IHCM calculated speed	IHCMV	km/h	42.6	11.83	36.4	9.48
IHCM degree of saturation	ISAT	ratio	0.62	0.214	0.63	0.22
HDM-4 traffic noise	TRAFN	m/ sec^2	0.336	0.184	0.318	0.18
HDM-4 relative flow	RELFLOW	ratio	0.624	0.202	0.629	0.218
Observed fuel per sec.	OBFUEL/SEC	ml / sec	0.994	0.447	2.99	1.89
Observed fuel per km.	OBFUEL/KM	ml / km	117.8	62.8	285	173.6
ARFCOM fuel per sec.	ARFUEL/SEC	ml / sec	0.937	0.406	2.91	1.56
ARFCOM fuel per km.	ARFUEL/KM	ml/ km	107.2	41.9	286	151.5
Vehicle Weight	WT	tonnes	1.5	-	11.79	1.43

An attempt was made to predict mean speed using both the Indonesian Highway Capacity Manual (IHCM) (Sweroad, 1997) and a study carried out by Holmgren and Rajokvic (1994). In both cases the estimated mean speeds for the Kijang (42.6 kph and 40.15 kph), were substantially above the observed speed of 34.7 kph. For the truck, the observed speed was much closer (at 38.8 kph) to the calculated speeds of 36.4 km/h for both studies. There is no simple explanation of why the Kijang speeds were 4 kph lower than for the truck. It is possible that junction delays, unrecorded traffic, and variations in road side friction (including street parking and the effects of two short lengths of road works) may, when added together, provide the explanation. However no dominant delaying factors were noticed by the survey team and, as Figure 1 shows, a wide variation of speeds were observed.

Regressions relating observed speed to traffic and road characteristics and to the IHCM calculated speed are presented in Table 2. Although significant results were obtained R^2 values were relatively low indicating the difficulty of predicting vehicle speeds in congestion.

Table 2 Regressions Predicting Mean Vehicle Speeds (30 second interval analysis)

1) Kijang (V) = 55.82 - 0.296 RISE + 0.1139 FALL -0.263 CURV + 1.498 RW-1.748 RFI -0.01279 TRAF
(10.2) (3.5) (62.6) (20.5) (3.6) (12.8)

R^2 = 0.395, Mean Y= 34.7, St Error Y = 11.49, Observations: 1335

2) Kijang (V) = 3.31 + 0.7363 IHCMV
(26.8)

R^2 = 0.349, Mean Y= 34.7, St Error Y = 11.9, Observations: 1335

3) Truck (V) = 58.22 - 0.26 RISE + 0.149 FALL -0.021CURV + 1.476 RW -4.33 RFI - 0.00228 TRAF - 1.2 WT
(10.4) (5.7) (6.0) (25.4) (11.4) (3.6) (6.9)

R^2 = 0.453, Mean Y = 38.81, St Error Y = 10.13, Observations = 1676

4) Truck (V) = 7.868 + 0.85 IHCMV
(29.9)

R^2 = 0.347, Mean Y= 38.81, St Error Y = 11.04, Observations: 1676

Figures in brackets indicate T values.

4. ACCELERATION NOISE

In congested conditions vehicle acceleration has an important influence on fuel consumption. In the HDM-4 fuel consumption model acceleration noise (the standard deviation of vehicle accelerations, measured second by second) has been highlighted as a critical variable (Greenwood and Bennett, 1995, 1996). Using the test section data acceleration noise was calculated for each 30 second interval. A four minute interval analysis was also undertaken to see whether the results were sensitive to different analysis time periods.

Greenwood and Bennett suggest that acceleration noise comprises of two components, traffic noise (due to fast moving vehicle interactions) and natural noise (ascribed to the vehicle and road.) This is represented in the following equation.

$$\sigma a = \sqrt{\sigma\, at^2 + \sigma\, an^2}$$

Where σa is total acceleration noise in m/s ^{2}
σat is traffic noise in m/s^2
σan is natural noise in m/s^2

Traffic noise is considered to be a function of relative traffic flow and is derived from the following equations:

$$\sigma\,\mathrm{at} = \sigma\,\mathrm{atmax}\frac{1.04}{1 + e^{(a0+a1\,RELFLOW)}}$$

$$RELFLOW = \frac{Q}{Qult}$$

$$ao = 4.2 + 23.5\left(\frac{Qo}{Qult}\right)^2$$

$$a1 = -7.3 + 24.1\left(\frac{Qo}{Qult}\right)^2$$

Q	is traffic flow in passenger car space equivalents (PCSE) per hour
Qult	is the ultimate capacity of the road in stable flow in PCSE per hour
Qo	is the flow level below which traffic interactions are negligible in PCSE per hour
σatmax	is the maximum traffic noise estimated to be 0.6 m/s^2

Using the speed flow parameters for different road widths reported by both Greenwood and Bennett and by Hoban et al (1994) (eg for 7 m two lane road Qo/Qult is 0.1 and Qult is 2800 PCSE/h) traffic noise was estimated. The relationship between the calculated traffic noise and the observed acceleration noise was found to be very weak. For the 30 second analysis R^2 values were about 0.05 and for the four minute analysis these dropped to 0.03. The results of 30 second analysis are given in Table 2. Although the natural noise component could not be directly estimated, the additional explanation of factors such as roadside friction (regarded as partly contributing to natural noise) were not significant. The results indicate that acceleration noise is dependent on traffic speed and, for the truck, vehicle weight. High vehicle speeds and high vehicle weights lead to lower acceleration noise.

It has been suggested that spurious results can be obtained with a limited period analysis because acceleration noise may be correlated with net acceleration over the period and that longer time periods are required for a satisfactory analysis. In fact for the four minute analysis no statistical correlation (R^2=0) was found between net acceleration and acceleration noise, and for the 30 second analysis the relationship was very weak (R^2 = 0.05).

Table 2. Regressions Predicting Acceleration Noise (30 second interval analysis)

5) Kijang ACCN = 0.697- 0.00528 V - 0.000031 TRAF - 0.000225 RISE
(21.6) (3.16) (0.837)

R^2 = 0.273, Mean Y = 0.45, St Error Y = 0.125, Observations: 1335

6) Kijang ACCN = 0.391 + 0.174 TRAFN
(8.19)

R^2 = 0.0479, Mean Y = 0.45, St Error Y = 0.143, Observations: 1335

7) Truck ACCN = 0.881 - 0.0039 V+ 0.0000233 TRAF - 0.00133 RISE - 0.0297 WT
(20.1) (4.08) (6.32) (16.4)

R^2 = 0.278, Mean Y = 0.416, St Error Y = 0.104, Observations: 1676

8) Truck ACCN = 0.365 + 0.16 TRAFN
(9.9)

R^2 = 0.055, Mean Y = 0.416, St Error Y = 0.119, Observations: 1676

Figures in brackets indicate T values.

5. FUEL CONSUMPTION

Histograms of the observed fuel consumption of the Kijang and Medium truck are presented in Figures 3 and 4. As expected, the histograms indicate that a much wider spread of observations were recorded for the truck than for the Kijang.

As part of the analysis, recorded fuel consumption was compared with the predicted fuel consumption estimated from Australian Road Research Board's ARFCOM model. In this model, fuel consumption is predicted from data relating to each vehicle type together with data on the road gradient and curvature and a second-by-second speed profile. Precise data on engine characteristics and a number of other parameters were not available and inevitably "default" data had to be used. Overall, for the 28 Kijang test runs, the observed fuel consumption for the Kijang was 47.7 litres compared with the estimate of 45 litres from ARFCOM. For the 32 test runs of the truck, total fuel consumption was estimated to be 150.2 litres compared 146.3 litres predicted by ARFCOM. So overall, with the input data used ARFCOM underestimated total fuel consumption by 6 % for the Kijang and by about 3% for the truck. (In comparison it was estimated that HDM III would have overestimated fuel consumption by about 70% for the Kijang at 35 kph). If more information had been available to give a better calibration there is every reason to believe that ARFCOM's predictions would have been even closer to the observed. R^2 values between observed fuel consumption (per second) and ARFCOM's predictions were estimated to be 0.77 for the Kijang and 0.76 for the medium truck.

Regressions relating the observed fuel to road geometry, speed, net vehicle acceleration, acceleration noise and vehicle weight were carried out. The four minute analysis gave relatively better fits; the results are given in Tables 3 and 4. The Tables also show the relationship between fuel consumption predicted by ARFCOM to other factors.

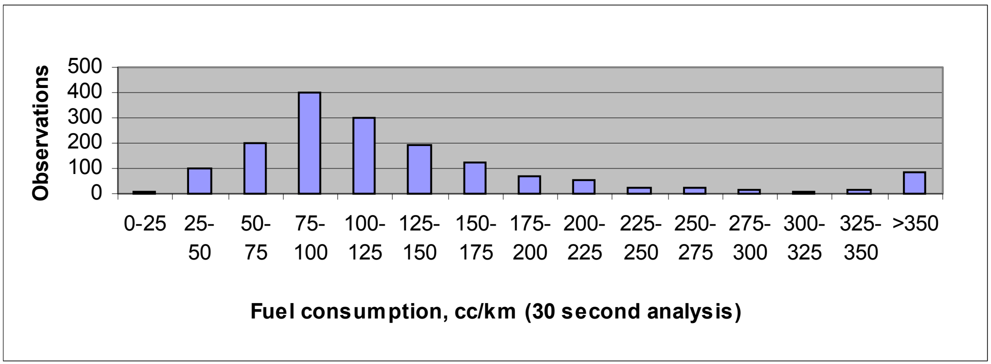

Figure 3. Fuel Consumption Distribution for Kijang Light Vehicle

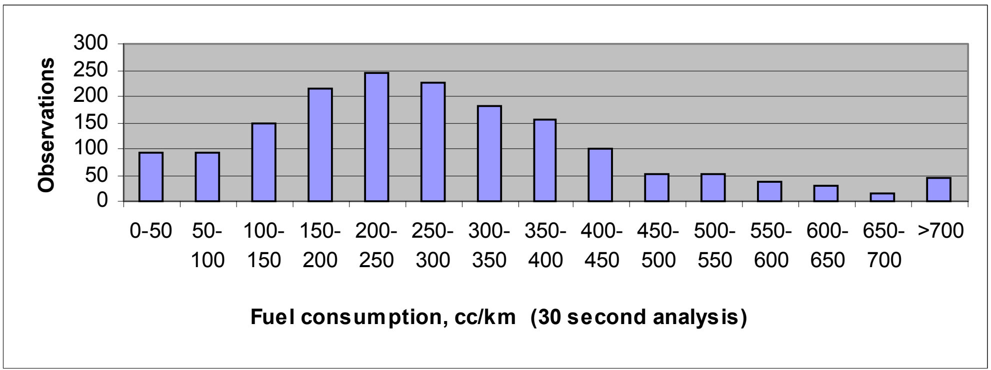

Figure 4. Fuel Consumption Distribution for Medium Truck

Table 4. Kijang Fuel Consumption Regression Equations (four minute analysis)

9) OBFUEL/KM= 24.5 + 1348.2/V + 0.00614 V^2 + 1.665 RISE + 1.418 FALL + 183.7 ACC + 58.1 ACCN
(30.6) (4.3) (23) (18.4) (8.36) (5.23)

R^2 = 0.95, Mean Y = 109.6, St Error Y = 8.47, Observations 160

10) OBFUEL/KM = 55.9 + 1317.6/V + 0.00378 V^2 + 1.7 RISE + 1.39 FALL + 174 ACC
(27.9) (2.59) (21.8) (16.7) (7.34)

R^2 = 0.941, Mean Y = 109.6, St Error Y = 9.17, Observations 160

11) ARFUEL/KM = 42.1+ 1022.2/ V+ 0.0073 V^2 + 1.267RISE +1.44 FALL+ 0.0138 $FALL^2$ + 88.36 ACC
(45.1) (10) (34.1) (10.6) (3.58) (7.32)

+ 28.83 ACCN
(5.13)

R^2 = 0.975, Mean Y = 101.6, St Error Y = 4.28, Observations 160

12)ARFUEL/KM = 57.38+ 1008.7/ V + 0.00618 V^2 + 1.286 RISE + 1.38 FALL+ 0.0124 $FALL^2$ + 81.86 ACC
(41.5) (8.24) (32.2) (9.46) (3) (6.32)

R^2 = 0.971, Mean Y = 101.6, St Error Y = 4.62, Observations 160

Figures in brackets indicate T values.

Table 5. Truck Fuel Consumption Regression Equations (four minute analysis)

13) $OBFUEL/KM = 48.81 + 992.5/V + 0.02111\ V^2 + 0.786\ WT.RISE + 7.06\ FALL$

(2.02) (3.22) (38) (8.41)

$+ 0.0741 FALL^2 + 53.8\ WT.RISE + 58.1\ WT.ACCN$

(3.05) (8.75) (8.78)

$R^2 = 0.95$, Mean Y = 279.8, St Error Y = 26.35, Observations 196

14) $OBFUEL/KM = 205.5 + 1109/V + 0.0109\ V^2 + 0.728\ WT.RISE + 6.92\ FALL + 0.061 FALL^2 + 55.1 WT{*}\ ACC$

(1.9) (1.4) (31.3) (6.96) (3.05) (7.42)

$R^2 = 0.93$, Mean Y = 279.8, St Error Y = 31.2, Observations 196

15) $ARFUEL/KM = 44.23 + 1439/V + 0.01784\ V^2 + 0.688\ WT.RISE + 6.45\ FALL$

(5.86) (5.457) (66.5) (15.36)

$+ 0.0878\ FALL^2 + 51.9\ WT.ACC + 25.2\ ACCN$

(7.23) (16.9) (16.8)

$R^2 = 0.983$, Mean Y = 274.1, St Error Y = 13.2, Observations 196

16) $ARFUEL/KM = 193.9 + 1550/V + 0.00804 V^2 + 0.633\ WT.RISE + 6.3\ FALL + 0.0753\ FALL^2 + 52.2\ WT.ACC$

(41.5) (8.24) (32.2) (9.46) (3.94) (10.77)

$R^2 = 0.957$, Mean Y = 274.1, St Error Y = 20.8, Observations 196

Figures in brackets indicate T values.

The tables show that good overall fits could be obtained for both observed fuel consumption and for ARFCOM's predictions using regression analysis. For observed fuel consumption the R^2 value of 0.95 was found for both the Kijang and the truck; for ARFCOM an R^2 value of approximately 0.98 was found for both vehicles. If acceleration noise is dropped from the analysis (because of considerable difficulties in its prediction) the R^2 value falls to 0.94 and 0.93 for the observed fuel consumption and to 0.97 and 0.96 for ARFCOM.

The analysis indicates that, in congested conditions, good predictions of fuel consumption could be obtained from the application of a relatively simple multiple regression model provided there is a reliable basis for predicting mean vehicle speed. Although net acceleration is included in the analysis for most interurban road planning no net acceleration will be predicted and so this variable may be set to zero. It appears that little extra accuracy is added from the inclusion of acceleration noise.

6. CONCLUSIONS

The study has shown that substantial difficulties still remain with the modelling of vehicle speeds, for interurban roads in congested situations, within developing countries. Although significant results were obtained in modelling speeds from traffic volumes, roadside friction and other road based parameters, further work in this area is clearly required.

Acceleration noise (the standard deviation of second by second accelerations) was found to be a function of mean speed, traffic, and rise, and for the truck, vehicle weight; however only moderate statistical explanation was found. Once these had been taken into account, road width and roadside friction were not found to be significant. Only a statistically poor relationship ($R^2 = 0.05$) could be found between observed acceleration noise and traffic noise, calculated from the HDM-4 traffic volume capacity ratio. This may reflect the difficulty of predicting speeds in the first instance.

Overall, fuel consumption was found to be relatively close to that predicted by the Australian Road Research Board's ARFCOM model. Observed fuel was estimated to be about 6 per cent higher for the Kijang and 3 per cent higher for the truck than that predicted by ARFCOM.

A multiple regression analysis of fuel consumption was carried out and significant coefficients were identified for speed, rise, fall, net acceleration, acceleration noise. Weight (in association with rise, acceleration and acceleration noise) was also an important parameter for the truck. In the analysis it was found that a close fit could be found between ARFCOM's fuel consumption predictions and a multiple regression analysis of the same factors. It was found that only a small loss of accuracy would result if acceleration noise was omitted from the analysis.

The analysis indicates that a relatively simple multiple regression model can be used to satisfactorily predict fuel consumption under conditions of congestion on an interurban road. Mean vehicle speed is the most critical variable in the analysis. For most road planning purposes net acceleration can be taken to be zero, but, where speed changes can be anticipated net acceleration may be input into the models to calculate its effect on fuel consumption.

It is not known to what extent the relationships derived in Indonesia can be applied to other countries. The relationship between mean speed and speed variability (or acceleration noise) and hence fuel consumption might well be different in radically different environments.

This study has been limited to two vehicle types on a 17 km congested interurban road. It is clearly important to expand the study to include other vehicle types on different roads that can incorporate different road geometry.

7. ACKNOWLEDGEMENTS

The work described forms part of a joint programme of research carried out by the Infrastructure and Transportation Department of the Transport Research Laboratory's (TRL) International Division (Department Head T. Toole) and the Institute of Road Engineering in Bandung (Director Ir Frankie Tayu). The work was jointly funded by the World Bank under the Road Research Development Programme (RRDP), the UK Department for International Development (DFID) and the Directorate General of Highways (DGH).

Any views expressed are not necessarily those of DFID, the World Bank, or the DGH.

8. REFERENCES

Bennett CR (1996). Modelling the effects of traffic congestion on fuel consumption in HDM-4: overview of methodology and specifications. International Study of Highway Development and Management Tools (HDM-4).

Biggs DC (1988) ARFCOM - Models for estimating light to heavy vehicle fuel consumption. Research Report ARR No. 152, Australian Road Research Board, Vermont South, Victoria.

Greenwood ID and CR Bennett (1995). The effects of traffic congestion on fuel consumption. International Study of Highway Development and Management Tools (HDM-4)

Greenwood ID and CR Bennett (1996). The effects of traffic congestion on fuel consumption. Vol 5, No 2. Road and Transport Research.

Hoban C, W Reilly and R Archondo-Callao (1994). Economic Analysis of Road Projects with Congested Traffic. World Bank.

Holmgren CA and Rajkovic G. (1994). Effects of Increased Road width on Highways with Side Friction Impact in Semi-urban Areas on Java, Indonesia. Master's Thesis, Department of Road Traffic and Traffic Planning Chalmers University of Technology, Goteborg, Sweden.

ND Lea International Ltd (1997). Integrated Road Management Systems (IRMS), revised Road User Cost Model Manual, Working Paper Ministry of Public Works, Jakarta.

Sweroad (1997). Indonesian Highway Capacity Manual (IHCM), Directorate General Bina Marga, Directorate of Urban Road Development.