TRANSPORT COSTS FOR HIGHWAY PLANNING IN INDONESIA: RESULTS FROM NEW RESEARCH INTO SPEED AND FUEL CONSUMPTION IN CONGESTION, VALUES OF PASSENGER TIME AND VEHICLE MAINTENANCE COSTS

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1. INTRODUCTION

Despite the introduction of road planning models (such as the World Bank's Highway Development and Management Model, HDM-4) there is still considerable uncertainty about the validity of using existing vehicle operating cost models in different countries and the appropriate procedures for estimating passenger values of time. In order to address these issues three studies were undertaken covering speeds and fuel consumption, values of time and vehicle maintenance costs. Most of the field work was undertaken during 1996 and 1997.The research was carried out by the Institute of Road Engineering in Bandung in co-operation with the Transport Research Laboratory of the UK. The work programme was funded by the World Bank, the Department for International Development, UK and the Government of Indonesia.

2. SPEED AND FUEL CONSUMPTION

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 HDM-III) and road maintenance programs such as the Indonesian Integrated Road Management Systems (IRMS). In contrast much less is known about how fuel consumption varies with the speed changes brought about by traffic 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, second by second, from a speed profile input by the user. However little is known about the speed profiles of inter-urban traffic movements in developing countries.

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 17 km section of the heavily congested Nagreg to Cileunyi road, south east of Bandung. Road alignment, road width and traffic data were also collected for the study. In total 100,000 speed measurements (recorded second by second) and 10,000 fuel readings (recorded every 10 seconds) were collected over 1000 km of test runs. For the truck gross vehicle weight was changed on different days of the survey, the gross weights were 13.4, 12.2 and 9.95 tonnes respectively. Basic survey data is presented in Table 1. The data excludes observations when vehicles were at rest or travelling less than 5 km/h.

2.1 Vehicle Speeds

In the surveys a very wide range of speeds (i.e. from 0 to 80 kph) were observed. The modal observation was between 35 to 40 kph. As far as possible, the speed and fuel data were related to the associated road gradient, curvature, width and traffic (measured in passenger car space equivalents) and an index of roadside friction (to take account of parked vehicles, linear development etc.). A 30 second analysis period was used. For each run the traffic data was allocated into five sections along the length of the road. Table 2 gives the most significant regression results for predicting vehicle speed. It can be seen that although the results are very significant the R^2 values are not high at around 40-45%.

An attempt was made to predict mean speed using the Indonesian Highway Capacity Manual (IHCM) (Sweroad, 1997). The estimated mean speeds for the Kijang (42.6 km/h) was substantially above the mean observed speed of 34.7 km/h. For the truck, the observed speed was higher at 38.8 km/h than, but much closer to the IHCM calculated speed (36.4 km/h). The field surveys for the Kijang and the truck were undertaken on different days. No simple explanation could be found to indicate why the Kijang speeds (even after omitting speeds below 5 km/h) were, on average, 8 km/h slower than those predicted by the IHCM. It is possible that junction delays, unrecorded traffic, variations in roadside 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. The truck surveys were carried out in very similar conditions and, despite marginally higher traffic volumes, average speeds were 4 km/h higher than for the Kijang.

Table 1: Basic Survey Data (30 Second Intervals)

	Units	Kijang Light vehicle Mean	Kijang Light vehicle St. Dev.	Truck Mean	Truck St. Dev.
Observed speed (V)	Km/h	34.7	14.7	38.8	13.67
Acceleration	m / sec^2	0.0058	0.151	0.006	0.15
Rise	m / km	9.22	14.1	8.807	13.2
Fall	m / km	-7.59	12	-8.12	12.2
Curvature	deg / km	81.5	78.7	80.7	75.8
Road width	m	9.15	4.68	9.15	4.67
Roadside Friction Index	scale: 1-4	2.04	0.746	2.04	0.75
Traffic	pce / hr	1996	377.5	2025	467
IHCM calculated speed	km/h	42.6	11.83	36.4	9.48
Observed fuel per sec.	ml / sec	0.994	0.447	2.99	1.89
Observed fuel per km.	ml / km	117.8	62.8	285	173.6
ARFCOM fuel per sec.	ml / sec	0.937	0.406	2.91	1.56
ARFCOM fuel per km.	ml/ km	107.2	41.9	286	151.5
Vehicle Weight (t)	tonnes	1.5	-	11.79	1.43

Table 2: Regressions Predicting Vehicle Speed (30 Second Interval Analysis)

1) Kijang observed speed = 55.82 - 0.296 rise + 0.1139 fall -0.263 curv. + 1.498 width
(10.2) (3.5) (62.6) (20.5)

-1.748 friction -0.01279 traffic
(3.6) (12.8)

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

2) Truck observed speed = 58.22 - 0.26 rise + 0.149 fall -0.021curv. + 1.476 width
(10.4) (5.7) (6.0) (25.4)

-4.33 friction - 0.00228 traffic - 1.2 weight (t)
(11.4) (3.6) (6.9)

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

Note: figures in brackets are 'T' values

2.2 Fuel Consumption

Fuel consumption data (recorded at ten second intervals) was analysed together with the second-by-second speed profile data and the road geometry and traffic data. The results were compared with the fuel consumption predicted from the ARFCOM model. Precise data on engine characteristics and a number of other parameters were not available and "default" data had to be used. Overall for the 28 Kijang test runs the observed fuel consumption 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 observed to be 150.2 litres compared with 146.3 litres predicted by ARFCOM. Overall, ARFCOM was found to underestimate total fuel consumption by 6% for the Kijang and 3% for the truck. However, 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 values.

Two analysis periods were used; (30 seconds and 4 minutes), and the data were analysed using multiple regression. In the analysis it was possible to relate both the observed fuel consumption data and data generated from ARFCOM to vehicle speeds, road geometry, vehicle weight, and net acceleration. The results show that good overall fits were obtained using the regression analysis both for the observed data and for data generated by ARFCOM.

The results were compared with predictions from HDM-III (Watanata T et al.,1987) (HDM-III was used at the time in the Indonesian IRMS model). It was found that, for a flat straight road HDM-III grossly overestimated fuel consumption for the Kijang (by over 90% at 60 km/h) and by a somewhat lesser amount for the truck (i.e by around 60 % at 20 km/h and by 20 % at 60 km/h). The over-prediction of fuel consumption in HDM-III is now recognised and HDM-4 will use ARFCOM together with a simulated speed profile (Bennett, 1996). However the results show that provided one can predict average vehicle speeds accurately on a congested road (and the road geometry is known), there are good grounds for using a relatively simple multiple regression approach to predict vehicle fuel consumption. This has an obvious advantage for both simplicity of understanding and for local calibration. If, for a given road section, net acceleration can be predicted then the result may be input into the formula. If, as in most situations, it is believed that net acceleration will be zero then this term may be dropped from the formula.

Table 3: Fuel consumption

Kijang:

3) Ob. Fuel per km = 55.9 + 1317.6/V + 0.00378 V^2 + 1.7 rise + 1.39 fall + 174 acceleration
(240 secs) (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

4) Observed fuel per km = 57.14 + 1262.8/V + 0.00238 V^2 + 1.747 rise
(30 secs) (33.6) (2.1) (25.4)

+ 1.181 fall + 124 acceleration
(14.9) (21.2)

R^2 = 0.74, Mean Y = 117.8, St Error Y = 32.1, Observations: 1335

5) ARFCOM fuel per km = 57.38 + 1008.7/ V + 0.00618 V^2 + 1.286 rise + 1.38 fall
(240 secs) (41.5) (8.24) (32.2) (9.46)

+ 0.0124 fall^2 + 81.86 acceleration
(3) (6.32)

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

Truck:

6) Observed fuel per km = 205.5 + 1109/V + 0.0109 V^2 + 0.728 weight (t).rise + 6.92 fall
(240 secs) (1.9) (1.4) (31.3) (6.96)

+ 0.061 fall^2 + 55.1 weight(t). acceleration
(3.05) (7.42)

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

7) ARFCOM fuel per km = 193.9 + 1550/ V + 0.00804 V^2 + 0.633 wt* rise + 6.3 fall
(240 secs) (41.5) (8.24) (32.2) (9.46)

+ 0.0753 fall^2 + 52.2 wt* acceleration
(3.94) (10.77)

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

Note: figures in brackets are 'T' values

3. VALUE OF TIME

Information on the values of passenger time is required for both valuation and predictive purposes in transport and road planning. Many new road projects in Indonesia are for capacity expansion and journey time savings are the most important component of the benefits. Values of time are also needed to help predict mode and route choice. The value of passenger time savings will also be crucial to predicting how movement patterns will change following the construction of a new metro system or a new toll road.

Passenger values of time are usually split between "working time" and "non-working time". In most instances the former is usually valued in relation to wage rate plus an additional cost that covers the employers' extra costs of keeping someone in employment. The valuation of non-working time is more controversial. Earlier work in this area (principally carried out in the 1970's and early 1980's) had tended to suggest that non-working time was valued at about one third the wage rate. However, more recent work carried out in a number of developed countries suggests that the one-third rule is basically incorrect. It now appears that valuation of non working time is dependent on a wide range of cultural and socio-economic factors and that it is not a simple proportion of the wage rate. In the UK it appears that although the absolute value of time is less for the poor than for the rich the former have a higher ratio value of time to income than the latter.

3.1 Survey Procedure and Approach

In order to derive values of passenger time in Indonesia four separate surveys were undertaken in October 1997 using a "Stated Preference" approach. A survey of bus passengers was undertaken at the Kampung Rambutan bus terminal on the outskirts of Jakarta. Three other surveys of the occupants of cars and light vehicles were carried out at a petrol station (in South Central Jakarta); at a service station on the Jagorawi toll road, and at Cianjur on the main road between Bandung and Jakarta.

To identify the value of (non-working) time a series of paired choices were presented to each interviewee. The choices took the form of "Which would you prefer :

a) a reduction in journey time of 10 minutes
or b) a reduction in journey cost of 250 Rupiah (Rp)"

In the interview it was made clear that the choice had to be made on the basis that the interviewee paid for the journey and that it was carried out in their own time. It was found that up to six choice pairs (with different time and cost values) could be presented without an apparent drop in the respondent's enthusiasm to answer the questions. It was found that the most satisfactory approach to gain co-operation was to start the choice pair with an implicit low value of time and to vary the values in such a way that the value of time was progressively increased. In the example above the implicit value of time is equivalent to 1500 Rp per hour. If choice "A" is chosen then the person's value of time is greater than 1500 Rp per hour, and correspondingly if "B" is chosen then it is less than this. Ideally it was hoped that for most respondents there would be a switch from choosing time savings to cash savings as the implicit value of time was raised. In this way the point at which the switch is made between choosing time and cost savings will reveal the person's value of time.

Background information was collected on gender, age, family size, education level, occupation, household ownership of vehicles, travel purpose, travelling companions and who was paying for the journey. Information was also collected from the person's home address and on the current travel pattern. Because of the difficulty associated with asking about household income a better response was obtained by asking the respondent to estimate monthly household expenditure.

3.2 Survey Results

In total 621 useful interviews were undertaken from the four surveys (96 from the bus survey, 206 from the petrol station, 207 from the rural road and 112 from the toll road survey). Where it was not possible to properly carry out the stated preference part of the survey or where gross inconsistencies were observed, the questionnaire was omitted from the analysis.

In general co-operation was good and in most instances the interviewees had little difficulty in understanding the questions. The questions on household expenditure and on value of time preferences were answered quickly and well. However a major disappointment with the survey was the low number (41) of females interviewed.

In order to derive population estimates of the value of time, two main methods of analysis were used. Firstly, from individual values of time median values were calculated for the different surveys. Secondly, the data was analysed using a logit model to derive mean values of time and to determine the influence of other factors.

In Table 4 mean and median values of time and household expenditure levels are given for the different surveys. It can be seen that although the median income levels reported for the car survey were up to 5.5 times higher than for the bus survey the value of time of car occupants were approximately, only twice that of bus passengers. Wage rates were not directly surveyed, however on the basis of a conservative estimate of say, 50 hours work per month per household, for a household income of Rp 229,000 average income per bus passenger may be estimated at Rp 4580 per hour. On this basis bus passengers' non-working time can be calculated to be valued at 57% of the wage rate, which is clearly much higher than the previous estimates based on "one third of the wage rate".

Relatively small differences were found between the mean and median values of time for the bus passengers. Larger differences were found in the other surveys. This is particularly the case for the petrol station survey which had a large component of working drivers (44%) with lower income levels.

Table 4: Household Expenditure and Values of Time

Survey	Median Household Expenditure Rp/ month	Median Value of Time Rp/ hr	Mean Value of Time Calculated from Logit Analysis Rp/hr
Bus Station	229,000	2453	2756
Petrol Station	574,000	4000	6541
Rural Road	1,050,000	4469	5848
Toll Road	1,259,000	4188	5159

Figures 1 and 2 give percentage distributions of monthly expenditure and value of time. For the sake of simplicity the average of the three car surveys is presented. Table 5 presents the detailed results from the logit analysis.

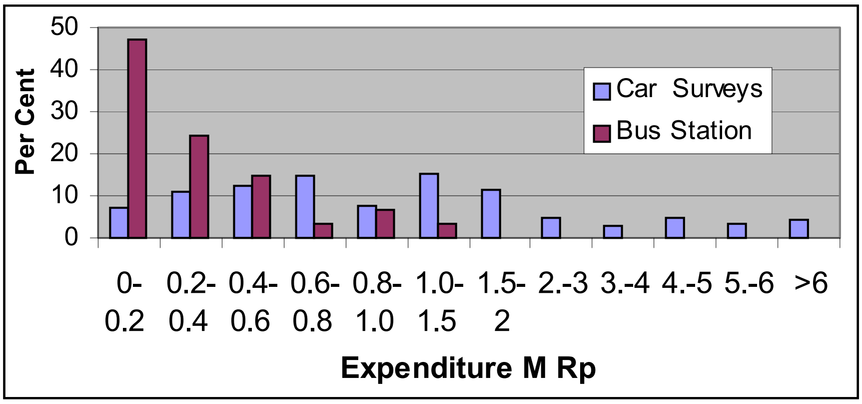

Figure 1: Distribution of Monthly Household Expenditure

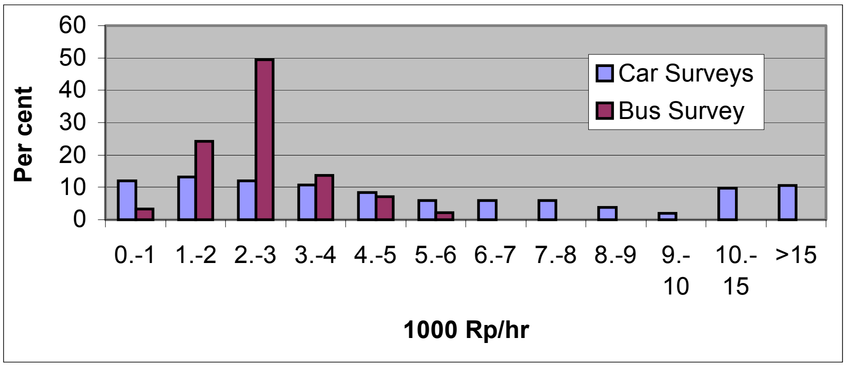

Figure 2: Distribution of Value of Time

Table 5: Logit Model Values of Time Using Combined Car Survey Data

Characteristic	Household Monthly Expenditure Rp. < 500 k	0.5- 1M	1-2 M	> 2 M	All
	Rp/hr	Rp/hr	Rp/hr	Rp/hr	Rp/hr
1. All Car Survey	3214*	5317	5749	8315*	5391*
2. Petrol Station	2080*	5236	10173	11860*	5056
3. Rural Road	5671	6270	4907	7105*	5849*
4. Toll Road	3032*	4161	6339	7913*	5153
5. Female	3233	7390	7833	10229*	7957*
6. Respondent > 35 yrs	2785*	4832	5083	7670*	5124
7. Household > 2 adults	2843*	5915	4973	7489*	5337
8. With Higher Education	5615	6439*	6903*	9720*	7344*
9. Car owning household	4283*	5831	5839	8257*	6135*
10. Respondent "at work"	3451*	5775	7771	9732	5934*
11. Work pays for journey	2908*	6212	6767	9994*	5440
12. With other passengers	4581	5464	5527	7665*	5707

* All coefficients are significant.

The logit analysis indicates that higher values of time are strongly associated with high levels of household expenditure. As might be expected expenditure levels below Rp 500,000 and above Rp 2 million per month provided the most significant differences from the estimated mean values of time. Higher values of time were also associated with being female, having higher education, and being a member of a car owning household.

The research has shown that a Stated Preference approach to valuing time in Indonesia can give consistent and useful results. However more research is clearly needed, particularly to investigate female values of time, and also to cover other parts of Indonesia. There is also a need to check on how values of time have changed with recent changes in the economy. Nevertheless, the results can still be used (after adjustments for inflation) for transport planning purposes.

4. VEHICLE MAINTENANCE COSTS

The relationship between vehicle maintenance costs and road roughness is a crucial component of the models of vehicle operating costs that are used in planning road investment and road maintenance. Highway investment models such HDM III, HDM-4 and the Indonesian Integrated Road Management System (IRMS) incorporate model relationships of vehicle operating costs in order to justify new road investment, the upgrading and rehabilitation of existing road surfaces and road maintenance standards.

The vehicle maintenance parts consumption/ road roughness relationship is perhaps the single most important relationship. Unfortunately it is also perhaps the most unstable relationship used in the models. Studies conducted in different countries indicate that the sensitivity of maintenance costs to road roughness varies markedly between different countries (for example see Cundill et al., 1997). The explanation of the nature of this variation between countries is not fully understood but it seems likely to relate to a combination of factors including differences in the ratio of prices between new vehicles and spare parts, and to differences in driving speeds, maintenance regimes and in the nature of road roughness (eg the absence or presence of severe pot holes).

It is for the above reasons that it is extremely important to determine the relationship between maintenance costs and road roughness for each country or, if this is not possible, to at least calibrate the vehicle operating cost models to local conditions. The new IRMS model that is currently used for road maintenance planning in Indonesia is based on the vehicle operating cost relationships used in HDM that were originally derived from research in Brazil carried out in the late 1970's.

To investigate these issues further, surveys of different vehicle types (utility vehicles, small and large buses and small and large trucks) were undertaken in five locations in Indonesia including East, West and Central Java and Kalimantan and Sulawesi. The maintenance cost data and other data relating to the vehicles were collected from both road side interviews of drivers and, where possible, vehicle owners. Drivers and operators were asked which roads they most frequently used and for these, road roughness data was collected from the Indonesian Road Maintenance Management System.

4.1 Survey Results

Commercial operators tend to be reluctant to provide accounting data to researchers. There is a natural fear that data may be used for income tax purposes. For this reason it is often difficult to collect a substantial volume of reliable data on vehicle operating costs. The data that were collected were mostly based on estimates of drivers and operators and therefore cannot be regarded as completely reliable. Nevertheless some useful results were obtained which can help us to determine approximate relationships and broad "ball park" estimates.

Road planning models split maintenance costs into parts and labour. The bulk of maintenance costs come from the consumption of spare parts and it is this item that is identified. Many operators use their own staff to fit parts and in the survey it was not possible to determine the value of mechanic labour time used.

The key parameters for predicting maintenance parts consumption are: new vehicle value, vehicle age, annual distance driven and road roughness. Mean values are presented in Table 6. It was decided to split data for buses into those with less than 40 seats (small buses) and those with more (large buses). Likewise, truck data was split between those vehicles licensed to take between 3 and 10 tonnes (small trucks) and those that take more than 10 tonnes (large trucks). Road roughness values varied from location to location. The maximum roughness value found was 12 IRI (for small buses) the maximum IRI found for large trucks and large buses was only just over 5 IRI. The latter vehicles tend to do long journeys on the main road network that naturally tend to have good road surfaces. For these reasons it is important not to extrapolate the maintenance cost relationships far beyond these values.

Table 6: Mean Survey Values for Different Vehicles

	Obs. No.	IRI M/km	Age Yrs	Km/yr	New vehicle Value Rp.	Parts per year Rp.	Parts per km Rp/km
Utilities:	387	3.93	9.65	90,223	20,624,740	1,132,729	16.57
Small Buses	146	4.92	4.18	117,211	50,951,459	5,647,507	62.52
Large Buses	161	4.05	6.04	137,026	116,443,478	4,899,963	42.43
Small Trucks	241	4.17	5.9	155,598	53,667,012	3,280,217	36.48
Large Trucks	153	3.89	4.9	182,239	73,385,135	3,386,757	36.48

Results of the regression analysis are given in Table 7. A variety of regression model forms were explored. In the table the value of parts consumption per km is the dependent variable. The independent terms shown are the most significant variables. Apart from the case of utility vehicles, road roughness was found to be a significant variable for all vehicle types, although the overall significance of the regression equations was found to be weak. As expected relatively low R^2 values were derived.

A common model form, used in the analysis of vehicle maintenance costs, is to make the dependent variable a ratio of parts consumption (per km) to new vehicle value. Although this model form is insensitive to inflation and it may be easily transferred for application in different countries it was found that this model form tended to <u>increase</u> the variability of parts consumption per km, measured in terms of the coefficient of variation. Hence in an Indonesian context, provided inflation data could be obtained, little would be gained by modelling parts consumption per km divided by vehicle value.

Better explanations (i.e. higher R^2 values) were found using non-linear regressions and by explaining parts consumption on a <u>per year</u> basis. Unfortunately space does not permit a full description of these results (for more information see Hine et al., 1998c). Also, it is more difficult to incorporate these alternative model forms into a road planning model without bias.

The results of the regression analysis were compared with IRMS cost predictions. For small buses the parts cost predictions were found to be virtually identical with IRMS predictions over the range of 2 to 8 IRI. For large buses, small trucks and utilities the IRMS predictions were 50 to 65 % higher (for an IRI of 6) than that observed. However for both large buses and large trucks a higher sensitivity to roughness was derived from the data than that calculated for the IRMS. The vehicle maintenance cost relationships in the IRMS have been based on HDM-III. Within the new HDM-4 model a greater emphasis has now been placed on local calibration. In addition, the sensitivity of the default option of the vehicle parts consumption to road roughness relationship has been reduced compared with that of HDM-III (Bennett, 1996).

Clearly further research is required in this area to confirm the findings of this research and to estimate with confidence the vehicle maintenance cost/ road roughness relationship. In order to make predictions of spare parts consumption, using the equations shown, it is necessary to adjust for inflation. The easiest method of doing this is to substitute the mean vehicle values given in Table 9 into the equations where appropriate and then to adjust the final result by an index of inflation taking July 1997 as the base date.

Table 9: Results of Regression Analysis

<u>Utilities</u>: 8) Parts per km = - 0.4065 + 0.259V.Value*10^{-6} + 0.842IRI + 0.864 Age
(4.11) (1.51) (4.52)
R^2 = 0.073, Mean Y = 16.57 St Error Y = 13.5, Observations = 384

<u>Small Buses</u>: 9) Parts per km = 61.67 - 0.97 V.Value*10^{-6} + 10.22 IRI
(2.83) (2.0)
R^2 = 0.057, Mean Y = 62.52 St Error Y = 53.5, Observations = 146

<u>Large buses</u>: 10) Parts per km = - 17.62 + 14.84 IRI
(8.47)
R^2 = 0.311, Mean Y = 42.43 St Error Y = 25.93, Observations = 161

<u>Small trucks</u> 11) Parts per km = - 2.268 + 6.963 IRI + 1.159 Age
(2.56) (2.05)
R^2 = 0.057, Mean Y = 33.63 St Error Y = 40.78, Observations = 241

<u>Large trucks</u>: 12) Parts per km = - 135.2 + 0.3172 V.Value*10^{-6} + 34.87 IRI + 2.636 Age
(3.28) (3.67) (2.56)
R^2 = 0.143, Mean Y = 36.48 St Error Y = 46.9, Observations = 148

Note: Figures in brackets are 'T' values.

5. CONCLUSIONS

The paper has outlined recent research carried out in Indonesia into three areas of transport planning that are particularly relevant to modelling the benefits of road investment. The main conclusions are as follows:

1) Despite substantial previous work, it is still difficult to forecast speeds accurately for a congested interurban road.
2) The ARFCOM model can give accurate estimates of fuel consumption for a congested road in Indonesia provided there is a basis for predicting vehicle speed profiles.
3) Alternatively, if average vehicle speeds can be predicted on a congested road a relatively simple multiple regression model can provide an accurate prediction of fuel consumption.
4) Acceptable and consistent results can be achieved in estimating the value of time using Stated Preference techniques in Indonesia.
5) Bus passengers value their “non-working” time more highly in relation to their income than richer car passengers and certainly at a rate that is higher than the previous widely accepted ratio of “one third of the wage rate”. In the surveys it was found to be in the region of 60% of the income level.
6) Although the statistical relationship between vehicle parts consumption and road roughness was found to be weak, evidence was found to confirm that the IRMS model (and the standard default version of HDM-III) overestimate vehicle maintenance costs at low levels of road roughness. The sensitivity of parts consumption to road roughness appeared to vary strongly between different vehicle types.

There is a clear need for further work in the areas covered. The main areas identified are:

a) Speed prediction on congested interurban roads
b) The fuel consumption research should be expanded to cover other vehicle types.

c) Value of time research using Stated Preference techniques should be deliberately targeted to include women and expanded to cover other parts of Indonesia.
d) To examine the sensitivity of investment decisions to estimates of the value of time.
e) Further research should be carried out to help identify the key relationships between vehicle maintenance costs and road condition. A more worthwhile approach may be to work closely with a few vehicle operators over relatively long periods of time.

A more detailed analysis of the findings of the research can be found in the Road Research Development Programme (RRDP) reports listed in the References.

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