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THE RESOURCE COSTS OF VEHICLE OPERATION IN CITIES: ESTIMATES FOR VENEZUELA

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CONTENTS

Page

I. INTRODUCTION 1

II. SUMMARY AND GUIDELINES FOR APPLICATION OF COSTS ESTIMATED 1

III. GENERAL EXPLANATORY NOTES 4

Table 1: Resource costs of tyre wear 6
Table 2: Resource costs of depreciation 7
Table 3: Resource costs of working time 8
Table 4: Resource costs of non-working time 9
Table 5: Resource costs of spare parts 10
Table 6: Resource costs of lubricants 11
Table 7: Resource costs of maintenance labour 12
Table 8: Resource costs of fuel consumption 13
Table 9: Resource costs of drivers and helpers 14
Table 10: Resource costs of freight transport time 14
Table 11: Cost adjustment factors for surface roughness 15
Table 12: Summary of resource costs, and comparison with costs estimated elsewhere 16
Table 13. Operating costs as summed from components and as derived from fitted equations 17

APPENDIX[1] Un modelo para estimar los beneficios por reducciones en el tamaño de flotas de vehiculos comerciales en la evaluacion de proyectos de mejoras al transito o transporte urbano. (A model to estimate the benefits from fleet size reduction for commercial vehicles in the evaluation of urban transit or transport improvement projects.) 18

[1]This appendix was drafted in Spanish.

I. INTRODUCTION

Vehicle operating costs in cities differ from those in non-urban conditions, largely because of what is known as the speed change cycle, i.e. the effect of stop/go and slow-down/speed-up phases which form an integral part of the phenomenon generally known as congestion. This significantly increases fuel, maintenance and other costs, especially at low average speeds, compared to what they would be at similar average speeds, but with lower variation around the mean, in interurban conditions.

Compared with the very detailed analyses which have been made of vehicle operating costs in interurban conditions, especially for application in the *Highway Design Model* developed by the World Bank, little research has been conducted into costs in urban conditions. This paper presents costs estimated for Venezuelan cities. The costs are estimated by component (personal time, fuel, tyres, etc.) and vehicle type (private car, trucks of different types, two sizes of buses, etc.).

Easy-to-use statistical relationships are fitted to total costs less personal time value (which can be simply assessed separately), giving costs as a function of average speed for each vehicle type. Note, however, that the fitted functions should not be used when average speeds are less than 10 km/hr or more than 60 km/hr.

Another innovation is a proposed methodology, presented in the appendix, for estimating the benefits from fleet size reductions brought about by increases in average speeds on commercial vehicle productivity. This methodology uses as input output from traffic simulation models and a few simple assumptions about local conditions.

II. SUMMARY AND GUIDELINES FOR APPLICATION OF COSTS ESTIMATED IN THIS PAPER

The economic (resource) costs of operating different types of road vehicle in Venezuelan cities, exclusive of personal times values (whether of paid crews or of passengers), in bolívares at March 1991 prices, are estimated to be as follows:

(i) Private car:

$$c_i = 4.6886e^{\frac{5.7480}{v_i}}$$

(ii) *Por puesto* (car):

$$c_i = 3.6137e^{\frac{7.4160}{v_i}}$$

(iii) Regular-size bus:

$$c_i = 12.2114e^{\frac{7.2600}{v_i}}$$

(iv) Minibus:

$$c_i = 7.2673e^{\frac{6.4380}{v_i}}$$

(v) Two-axle gasoline-powered truck:

$$c_i = 6.7711e^{\frac{7.0260}{v_i}}$$

(vi) Two-axle diesel-powered truck:

$$c_i = 8.1382e^{\frac{6.6480}{v_i}}$$

(vii) Three-axle truck:

$$c_i = 17.0963e^{\frac{5.9460}{v_i}}$$

(viii) Truck with more than three axles:

$$c_i = 25.2701e^{\frac{7.4100}{v_i}}$$

(ix) Long-wheelbase jeep:

$$c_i = 6.0943e^{\frac{6.6000}{v_i}}$$

where:

c_i = operating cost per kilometer for vehicles of type i (i = private car, car running as *por puesto*, regular-size bus, minibus, two-axle gasoline-powered truck, two-axle diesel-powered truck, three-axle truck, truck with more than three axles, or long-wheelbase jeep);

v_i = traffic speed for vehicles of type i.

The cost categories included are: (i) tyres, (ii) depreciation, (iii) spare parts, (iv) lubricants, (v) garage or workshop labour, and (vi) fuel.

To apply these costs in the economic evaluation of projects, traffic speed for vehicle type i should be read from the output of the traffic simulation model for each link or zone and entered in the above equations to determine the corresponding operating cost per vehicle kilometer. Total cost for vehicles of type i on any one link or in any one zone is estimated by multiplying the per vehicle-kilometer cost so determined and the number of vehicle-kilometers, which is obtained directly from the traffic model.

The costs exclude: (i) personal time values and (ii) savings due to fleet size reduction made possible by improvements to traffic speeds.

The economic evaluation must take into account the time costs of crews (i.e., the drivers of trucks, *por puestos*, minibuses and jeeps, together with any helpers) plus any passengers travelling during working time. In order to estimate crew costs, the traffic model should be used to assess the number of vehicle hours, by vehicle type, to which the per hour costs shown in table 9 should be applied.

In order to take into account the time costs of passengers travelling in working hours, for each type of vehicle, the average number of passengers travelling within working hours should be estimated. These estimates should be multiplied by the corresponding number of vehicle hours, to derive the number of person hours for travellers within working time. To these person hours, the unit per hour costs of table 3 should be applied. Note that working time does not include time spent travelling to or from work places.

The economic evaluation may also take into account the time costs of passengers travelling outside their working hours, although the decision to include this parameter in the evaluation depends on the prevailing policy of the financing organization to which the project is to be submitted. In order to assess such costs, the same procedure as indicated in the previous paragraph should be followed for people travelling outside working hours, and the unit hourly costs of table 4 applied.

Optionally, one may assess the time costs of freight in transit, using the unit costs of table 10. This is not normally done, since such costs are quantitatively of little importance.

Benefits from fleet size savings, due to the greater productivity of commercial vehicles made possible by higher traffic speeds, can be estimated by a separate procedure. A proposed methodology for this procedure is described in the appendix (drafted in Spanish).

The costs expressed by the equations presented above assume normal road surface conditions. In order to evaluate the benefits from improving the surface quality of paved urban roads, the factors shown in table 11 should be applied to the individual costs of tyres, spare parts, lubricants, workshop labour and fuel consumption presented in tables 1, 5, 6, 7 and 8, respectively. These factors do not take into account any speed changes caused by the impact of surface quality on driver behavior. Such changes must be estimated separately by the consultants and evaluated by means of the equations.

III. GENERAL EXPLANATORY NOTES

An estimation of vehicle operating costs is needed for the economic evaluation element of a series of transit and traffic management studies being contracted by the Ministry of Transport and Communications for a series of Venezuelan cities.

Vehicle operating costs have been estimated for urban conditions in Venezuela before, for example, by the late Robley Winfrey and the present author for the Caracas Road Pricing study conducted in 1971 and 1972. More recently, Joaquín Caraballo and Jorge Kohon (1991) have prepared a paper entitled *La adaptación local del modelo HDM del Banco Mundial en vías rurales y urbanas en Colombia y Venezuela*. This title is somewhat misleading, since the paper does not deal with vehicle operating costs in urban conditions in Venezuela. It does, however, include useful information on the economic costs of inputs and on vehicle characteristics, upon which a part of the estimates presented in the present document were derived.

The basic cost estimates are reproduced as a series of eleven tables:

Table 1. Resource costs of tyre wear per km, in bolívares at March 1991 values
Table 2. Resource costs of depreciation in bolívares at March 1991 values
Table 3. Resource costs of working time in bolívares at March 1991 values
Table 4. Resource costs of non-working time in bolívares at March 1991 values
Table 5. Resource costs per km of spare parts, in bolívares at March 1991 values
Table 6. Resource costs per km of lubricants, in bolívares at March 1991 values
Table 7. Resource costs per km of maintenance labour, in bolívares at March 1991 values
Table 8. Resource costs per km of fuel consumption, in bolívares at March 1991 values
Table 9. Resource costs per hour of drivers and helpers, in bolívares at March 1991 values
Table 10. Resource costs per hour of cargo carried by trucks, in bolívares at March 1991 values
Table 11. Resource cost adjustment factors for varying surface roughness.

Table 12 shows, for illustrative purposes, the estimated costs, at both 10 km/hr and 60 km/hr, for two of the vehicle types included in the analysis, i.e. a private car and a diesel-powered two-axle truck. The same table also compares the costs estimated for cars with those estimated for cities in other countries.

Table 13 summarizes total operating costs, exclusive of personal time values, and compares them with the results obtained from the fitted estimating equations.

Finally, the appendix (drafted in Spanish) presents, both formally and via a numerical example, the proposed method to estimate the capital savings through reduction in the fleet size of commercial vehicles.

The reports used as references in the preparation of this paper are the following:

1. Caraballo, Joaquín, and Jorge Kohon (1991), *La adaptación local del modelo HDM del Banco Mundial en vías rurales y urbanas en Colombia y Venezuela*, June.
2. Chesher, A., and R. Harrison (1987), *Vehicle operating costs: Evidence from developing countries*, IBRD.
3. Hashimshony, Gidcon (1991), *Guidelines for calculating vehicle operating costs - VOC for urban conditions* (draft), August.
4. Venezuela, Central Bank (1990), *Informe Económico*.
5. Venezuela. Central Bank (1991), *Boletín mensual*, August.
6. Venezuela. Central Statistical and Information Office (1990), *Indicadores de la fuerza de trabajo: Primer semestre*.
7. Watanatada, Thawat, and others (1987a), *The Highway Design and Maintenance Model, volume 1*, IBRD.
8. Watanatada, Thawat, and others (1987b), *Vehicle speeds and operating costs: Models for road planning and management*, IBRD.

Other information was obtained personally from Joaquín Caraballo and Fernando Perera, of the Ministry of Transport and Communications of Venezuela.

The vehicle types for which costs are estimated are the following:

1. private gasoline-powered car – 1.2 tons empty weight;
2. gasoline-powered collective taxi (*por puesto*) – 1.65 tons empty weight;
3. diesel-powered regular-size bus – 8.1 tons empty weight;
4. diesel-powered small-size bus (minibus) – 3.27 tons empty weight;
5. gasoline-powered light two-axle truck – 3.12 tons empty weight;
6. diesel-powered heavy two-axle truck – 5.4 tons empty weight;
7. diesel-powered three-axle truck – 6.6 tons empty weight;
8. diesel-powered articulated truck with more than three axles – 14.73 tons empty weight;
9. gasoline-powered jeep with lengthened wheel base.

Truck types vary according to the city concerned. For instance, they are smaller on average in the central zones of Caracas than in cities such as Ciudad Guayana or Valencia, which are either industrialized or subject to through traffic. Therefore, the consultants for each city should derive weighted averages of the costs calculated, as best may fit the local truck mix.

Table 1

RESOURCE COSTS OF TYRE WEAR
(Bolívares/km, at March 1991 values)

VEHICLE TYPE	RESOURCE COST AT INDICATED SPEED					
	10 km/hr	20 km/hr	30 km/hr	40 km/hr	50 km/hr	60 km/hr
Private car	0.0738	0.1162	0.1538	0.1868	0.1836	0.1601
Por puesto (car)	0.0954	0.1502	0.1989	0.2415	0.2375	0.2070
Regular-size bus	0.2895	0.4558	0.6036	0.7330	0.7207	0.6283
Minibus	0.3029	0.4769	0.6316	0.7669	0.7540	0.6574
Two-axle gasoline truck	0.3673	0.5783	0.7659	0.9300	0.9143	0.7971
Two-axle diesel truck	0.4923	0.7751	1.0265	1.2464	1.2255	1.0684
Three-axle truck	1.4253	2.2441	2.9719	3.6087	3.5481	3.0932
Truck w. more than three axles	1.8326	2.8854	3.8212	4.6400	4.5620	3.9771
Long-wheelbase jeep	0.1500	0.2362	0.3128	0.3798	0.3734	0.3255

Notes on sources and methodology

1. Basic tyre-wear estimates for cars were taken from Hashimshony, table VI-1. That study makes a quite detailed analysis in the case of cars but makes no comparable analysis for other vehicle types. It goes on to suggest that the variation of wear according to speed estimated for cars be also applied to other vehicle types. This was the approach adopted for the present paper.

2. Unit tyre costs were taken from Caraballo and Kohon (1991), table 4B.

3. No data are readily available for jeep tyre wear or unit values. The jeep costs were set at 57% more than those for the car-type *por puesto*.

4. It was assumed that private cars do not use retreaded tyres but that 75% of the tyres of other vehicles are retreaded once, that the life of a retread is 33% of that of a new tyre and that the retread cost is 25% of the cost of a new tyre.

Table 2

RESOURCE COSTS OF DEPRECIATION[a]
(Bolívares at March 1991 values)

VEHICLE TYPE	TAX-FREE PRICE IN VENEZUELA *(Bolívares)*	INTERNA-TIONAL TAX-FREE PRICE *(Resource cost)*	LIFE *(Years)*	LIFE *(Km)*	RESIDUAL VALUE *(% of resource cost)*	DEPRECIA-TION/KM *(Bolívares)*
Private car	731 500	548 625	15.0	200 000	7.5	2.5374
Por puesto (car)	750 000	562 500	15.0	500 000	7.5	1.0406
Regular-size bus	4 750 000	3 562 500	20.0	800 000	15.0	3.7852
Minibus	2 850 000	2 137 500	17.5	700 000	10.0	2.7482
Two-axle gasoline truck	1 425 000	1 068 750	10.0	600 000	15.0	1.5141
Two-axle diesel truck	2 109 000	1 581 750	12.5	550 000	15.0	2.4445
Three-axle truck	4 275 000	3 206 250	15.0	800 000	15.0	4.9551
Truck with more than three axles	4 987 000	3 740 000	15.0	600 000	15.0	5.2983
Long-wheelbase jeep	1 500 000	1 125 000	10.0	400 000	10.0	2.5313

[a]Benefits from reductions in the costs of capital tied up in vehicles, attributable to higher travel speeds, are dealt with in the appendix.

Notes on sources and methodology

1. The costs in the second column are taken from Caraballo and Kohon (1991), except for the jeep, which is not dealt with in that source. Long-wheelbase jeeps are not marketed in Venezuela at the present time, although they are virtually the only vehicles used on steep routes in marginal suburbs around Caracas. The cost stated is an estimate of what such a vehicle would cost if available.

2. The costs of the third column are estimated international values for the same vehicles, assessed at 75% of the domestic tax-free costs quoted in Caraballo and Kohon (1991).

3. The estimated vehicle lifetimes expressed in years are longer than normally assumed, but realistic in local conditions. They exceed those stated in Caraballo and Kohon (1991).

4. The residual values are expressed as a percentage of international values. The percentages were revised jointly with the Venezuelan Transport Council. Effectively, they are based on scrap values as a percentage of new vehicle, i.e. local tax inclusive, prices.

5. Depreciation per km is assessed on a straight line basis by dividing the international cost less residual value by the lifetime distance travelled.

Table 3

RESOURCE COSTS OF WORKING TIME
(Bolívares/hr, at March 1991 values)

CITY	BUS	*POR PUESTO*	AUTO
Caracas	90	116	147
Barquisimeto	73	96	131
Valencia	86	111	137
Maturín	80	100	120
Ciudad Guayana	93	124	163
Maracaibo	74	94	112
Mérida	63	88	107

Notes on sources and methodology

1. Social security and related costs were assessed at 35% of wage rate.

2. Overhead and related administrative costs borne by the employer were assessed at 20% of the wage rate of bus travellers, 25% for *por puesto* users and 30% for car occupants.

3. Wage rates were taken from Venezuela, Central Statistical and Information Office (1990), table 4, regional section.

4. Venezuela, Central Statistical and Information Office (1990), refers to the first semester of 1990. Values were adjusted to estimated March 1991 equivalents by the consumer price index taken from Venezuela, Central Bank (1991), with an extra 2.5% being added to allow for real wage increases.

5. Wage rates for users of different modes were assessed in the following way: The regional income distribution of non-agricultural workers was taken from Venezuela, Central Statistical and Information Office (1990). The rate for bus users was taken to be the income corresponding to the person 25% of the way up the scale, starting from the lowest wage rate; *por puesto* travellers were assumed to correspond to the median wage, and car occupants to the wage of the person 75% up the scale.

6. A working month of 160 hours was universally assumed.

Table 4

RESOURCE COSTS OF NON-WORKING TIME
(At March 1991 values)

Non-working travel time value for adults	30 bolívares/hr
Travel time for children and students	9 bolívares/hr

Notes on sources and methodology

1. Basic wage levels taken from table IV-39 of Venezuela, Central Bank (1990).
2. Annual salaries are assumed to be 14 times monthly salaries, with 160 working hours being used to calculate hourly equivalents.
3. Inflation from average 1990 to March 1991 was assessed at 23%, by referring to Venezuela, Central Bank (1991). An extra 2.5% was added to reflect real wage rate increases.
4. Non-working time for adults was assessed at 30% of national wage rate, for all cities. Children/student's time was assessed at 30% of the adult value. Walking and waiting time values were not assessed.

Table 5

RESOURCE COSTS OF SPARE PARTS
(Bolívares/km at March 1991 values)

VEHICLE TYPE	RESOURCE COST AT INDICATED SPEED					
	10 km/hr	20 km/hr	30 km/hr	40 km/hr	50 km/hr	60 km/hr
Private car	2.6238	1.6005	1.2416	1.0631	1.0233	1.0233
Por puesto (car)	2.7690	1.6891	1.3103	1.2220	1.0799	1.0799
Regular-size bus	7.9445	4.8461	3.7593	3.2191	3.0984	3.0984
Minibus	4.7668	2.9077	2.2556	1.9315	1.8590	1.8590
Two-axle gasoline truck	3.3398	2.0372	1.5804	1.3533	1.3025	1.3025
Two-axle diesel truck	5.5363	3.3771	2.6198	2.2433	2.1591	2.1591
Three-axle truck	12.024	7.3343	5.6895	4.8719	4.6892	4.6892
Truck w. more than three axles	23.379	14.261	11.063	9.4732	9.1178	9.1178
Long-wheelbase jeep	3.6738	2.2409	1.7384	1.4886	1.4328	1.4328

Notes on sources and methodology

1. The costs were derived by taking a base case parts consumption estimated from table 15D of Watanatada and others (1987b), factored according to table VIII-3 of Hashimshony.

2. This procedure yields parts costs as a function of the cost of new vehicles. These latter costs were taken from table 2 of the present paper.

3. Costs for jeep parts were set at 10% more than those for the light gasoline-powered truck.

Table 6

RESOURCE COSTS OF LUBRICANTS
(Bolívares/km at March 1991 values)

VEHICLE TYPE	RESOURCE COST AT INDICATED SPEED					
	10 km/hr	20 km/hr	30 km/hr	40 km/hr	50 km/hr	60 km/hr
Private car	0.1142	0.0865	0.0796	0.0762	0.0727	0.0692
Por puesto (car)	0.1315	0.0969	0.0865	0.0796	0.0779	0.0762
Regular-size bus	0.3900	0.2918	0.2591	0.2427	0.2345	0.2264
Minibus	0.2918	0.2182	0.1936	0.1827	0.1773	0.1691
Two-axle gasoline truck	0.1454	0.1073	0.0969	0.0865	0.0848	0.0831
Two-axle diesel truck	0.2918	0.2182	0.1936	0.1827	0.1773	0.1691
Three-axle truck	0.3900	0.2918	0.2591	0.2427	0.2345	0.2264
Truck w. more than three axles	0.4227	0.3164	0.2809	0.2618	0.2536	0.2455
Long-wheelbase jeep	0.1454	0.1073	0.0969	0.0865	0.0848	0.0831

Notes on sources and methodology

1. The costs for private cars were calculated from the consumption figures in table VII-1 of Hashimshony and unit economic costs reproduced in table 4B of Caraballo and Kohon (1991).

2. Hashimshony estimates oil consumption separately for replacement and replenishment. For other vehicle types, the following adjustment factors were applied to the replenishment/refilling consumptions: *por puesto* (car) – 1.00/1.25; regular bus – 3.00/3.75; minibus – 2.25/2.8125; two-axle gasoline-powered truck – 1.00/1.50; two-axle diesel-powered truck – same as minibus; three-axle truck – same as regular bus; truck with more than three axles – 3.25/4.0625; jeep – same as two-axle gasoline-powered truck. These factors are based on the sump capacities of the different vehicle types and, in a more arbitrary way, on the greater oil burn, considering the likelihood that *por puestos* have piston rings more worn than those of an equivalent private car, etc.

Table 7

RESOURCE COSTS OF MAINTENANCE LABOUR
(Bolívares/km at March 1991 values)

VEHICLE TYPE	RESOURCE COST AT INDICATED SPEED					
	10 km/hr	20 km/hr	30 km/hr	40 km/hr	50 km/hr	60 km/hr
Private car	0.9128	0.5568	0.4319	0.3698	0.3560	0.3560
Por puesto (car)	0.9500	0.5795	0.4495	0.3849	0.3705	0.3705
Regular-size bus	3.1950	1.9490	1.5119	1.2946	1.2461	1.2461
Minibus	1.9170	1.1694	0.9071	0.7768	0.7476	0.7476
Two-axle gasoline truck	2.6075	1.5906	1.2359	1.0566	1.0169	1.0169
Two-axle diesel truck	2.7938	1.7042	1.3220	1.1320	1.0896	1.0896
Three-axle truck	3.5500	2.1635	1.6799	1.4385	1.3845	1.3845
Truck w. more than three axles	10.156	6.1967	4.8070	4.1162	3.9618	3.9618
Long-wheelbase jeep	1.7788	1.0851	0.8427	0.7208	0.6937	0.6937

Notes on sources and methodology

1. Unit labour costs were taken from table 4B of Caraballo and Kohon (1991).

2. Base-situation maintenance labour inputs were derived from table 15D of Watanatada and others (1987b). These were then factored to equivalents at different speeds in urban conditions using figures from table VIII-3 from Hashimshony (1991).

3. No information was available for jeeps. The costs for jeeps were assumed to be the arithmetic average of those for *por puestos* (car) and two-axle gasoline trucks.

Table 8

RESOURCE COSTS OF FUEL CONSUMPTION
(Bolívares/km at March 1991 values)

VEHICLE TYPE	RESOURCE COST AT INDICATED SPEED					
	10 km/hr	20 km/hr	30 km/hr	40 km/hr	50 km/hr	60 km/hr
Private car	2.0306	1.4383	1.2437	1.1422	1.0691	1.0153
Por puesto (car)	2.5391	1.7985	1.5552	1.4282	1.3368	1.2696
Regular-size bus	9.3814	6.6449	5.7459	5.2770	4.9392	4.6907
Minibus	3.7363	2.6465	2.2884	2.1016	1.9671	1.8682
Two-axle gasoline truck	5.5842	3.9553	3.4202	3.1411	2.9400	2.7921
Two-axle diesel truck	4.1830	2.9629	2.5620	2.3529	2.2023	2.0915
Three-axle truck	8.6301	6.1128	5.2857	4.8544	4.5437	4.3150
Truck w. more than three axles	11.595	8.2127	7.1015	6.5220	6.1046	5.7974
Long-wheelbase jeep	3.4317	2.4307	2.1019	1.9303	1.8068	1.7159

Notes on sources and methodology

1. Unit fuel costs were taken from table 4B of Reference 1. After comments that these might be too low, they were compared with the Venezuelan export price of gasoline, obtained via the Venezuelan Transport Council, and were found to be of the same order of magnitude and, hence, were not amended. As a further check, table 15-2 of the April 1992 edition of *Oil and Energy Trends* informs that the spot U.S. Gulf Coast price of regular motor gasoline was US$ 0.6595/gallon in March 1991. This equates to US$ 0.1742 or 9.41 bolívares per litre. Since the unit costs used fluctuate around 9.00 bolívares per litre (depending on product grade), it was concluded that they are essentially correct.

2. Fuel variation for cars as a function of speed under urban conditions was derived from table V-5 of - Hashimshony. The figures of this table were modified arbitrarily, since it does not appear to allow for speed change cycles that do not reduce speed to zero, but rather to a lower but still positive speed.

3. Hashimshony treats in some detail the relationship between car fuel consumption and speeds in urban conditions, but covers very superficially corresponding relationships for other vehicle types. Enquiries were made to locate other sources which might go into the subject more thoroughly, but no sufficient response had been obtained by the time the third edition of this paper was being prepared. Therefore the following factors were calculated to adjust the car fuel cost per km to equivalents for other vehicles. They are the joint product of relative (to the car) mean loaded weight of the vehicle concerned and relative fuel price, with a reduction of 25% in the case of diesel powered vehicles. (The vehicle weights were estimated from table 1 of Caraballo and Kohon (1991), with a mean 60% loading assessed for freight-carrying vehicles.) No account was taken of less significant complicating factors, such as aerodynamic resistance. The factors are: regular-size bus – 4.62; minibus – 1.84; two-axle gasoline-powered truck – 2.75; two-axle diesel-powered truck – 2.06; three-axle truck – 4.25; truck with more than three axles – 5.71, and long-wheelbase jeep – 1.69.

4. There may be significant differences between the resource costs of fuel in different cities, due to transportation costs, but no information was available on which to make unit fuel costs city-dependent.

Table 9

RESOURCE COSTS OF DRIVERS AND HELPERS
(Bolívares/hr at March 1991 values)

VEHICLE TYPE	PERSONS IN CREW	UNIT LABOUR COST	COST/VEHICLE/HR
Private car	0	–	–
Por puesto (car)	1	75	75
Regular-size bus	1	75	75
Minibus	1	75	75
Two-axle gasoline truck	1	75	75
Two-axle diesel truck	1.5	75/60	105
Three-axle truck	2	75/60	135
Truck w. more than three axles	2	75/60	135
Long-wheelbase jeep	1	75	75

Notes on sources and methodology

1. In Caraballo and Kohon (1991), estimates are given of unit labour costs for vehicle drivers, but apparently ignores helpers, who ride with the drivers of the heavier trucks in Venezuela. The number of helpers was estimated and a unit cost of 60 bolívares/hr was assumed for them.

Table 10

RESOURCE COSTS OF FREIGHT TRANSPORT TIME
(Bolívares/hr, at March 1991 values)

VEHICLE TYPE	COST PER HOUR
Two-axle gasoline truck	250
Two-axle diesel truck	500
Three-axle truck	700
Truck with more than three axles	1 000

Notes on sources and methodology

1. Taken without modification from table 4B of Caraballo and Kohon (1991).

Table 11

COST ADJUSTMENT FACTORS FOR SURFACE ROUGHNESS (*QI*)

QI	LIGHT VEHICLES					HEAVY VEHICLES				
	Fuel	Oil	Tyres	Parts	Labour	Fuel	Oil	Tyres	Parts	Labour
25	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
75	1.06	1.28	1.28	1.60	1.46	1.00	1.09	1.28	1.94	1.39
125	1.21	1.56	1.67	2.58	2.07	1.09	1.19	1.67	2.97	1.74

Notes on sources and methodology

1. For fuel costs for the light vehicle, HDM fuel consumption for a light car on a paved, straight road was read at *QI* values of 25, 75 and 125, corresponding to speeds of 87, 83 and 71 km/hr, respectively. From Hashimshony, fuel consumption figures were interpolated for the same speeds at, implicitly, constant roughness. The consumption figure so derived at 87 km/hr was normalized, i.e. a factor was applied so that it gave the same consumption as the HDM, and the same factor was applied to the consumption figures at the two other speeds. It was assumed that the difference between the HDM consumption at each speed and the so-normalized consumption at the same speed was due to surface roughness differences. The factors tabulated are based on this premise. It is essentially supposed that the factor associated with each *QI* value is speed independent. The same basic procedure was followed in the case of the heavy vehicle, the HDM consumption figures used being those of the laden medium truck.

2. For oil consumption, TRRL relationships to estimate lubricant consumption as a function of roughness were used. These relationships are reproduced in Watanatada and others (1987a), page 185.

3. The factors relating tyre wear to roughness were derived directly from Hashimshony (1991), table VI-3, which took them in turn from a run of the HDM.

4. The parts consumption factors were derived from the graphs on page 182 of Watanatada and others (1987a).

5. The maintenance labour factors were derived from the graphs on page 184 of Watanatada and others (1987a).

Table 12

SUMMARY OF RESOURCE COSTS, AND COMPARISON WITH COSTS ESTIMATED ELSEWHERE
(Bolívares/km at March 1991 values)

TYPE OF COST	PRIVATE CAR		TWO-AXLE DIESEL TRUCK	
	10 km/hr	60 km/hr	10 km/hr	60 km/hr
Tyres	0.0738	0.1601	0.4923	1.0684
Depreciation	2.5374	2.5374	2.4445	2.4445
Spare parts	2.6238	1.0233	5.5363	2.1591
Lubricants	0.1142	0.0692	0.2918	0.1691
Garage labour	0.9128	0.3560	2.7938	1.0896
Fuel	2.0306	1.0153	4.1830	2.0915
Crew	–	–	10.5000	1.7500
Total	8.2926	5.1613	26.2417	10.7722
Total in US$	US$0.153	US$0.095	US$0.486	US$0.199
Costs estimated in 1983 for Kingston, Jamaica	US$0.160	US$0.145		
Costs estimated in 1983 for Lima, Peru	US$0.245	US$0.104		
Costs estimated in 1991 for Mexico City	US$0.258	US$0.091		
Costs estimated in 1991 for Bangkok, Thailand	US$0.206	US$0.103		
Costs estimated in 1989 for cities in the United Kingdom	US$0.180	US$0.111		

Notes on sources and methodology

1. The estimated costs for Venezuelan cities, as displayed in this table, exclude the opportunity costs of capital.

2. Fuel costs in Venezuela are comparatively low. Were they to be doubled, the car operating costs would become US$0.191 at 10 km/hr and US$0.114 at 60 km/hr.

3. Comparative costs for vehicles other than cars in cities in other countries are not available. The costs for cars were provided by Mr. John Cracknell.

Table 13

OPERATING COSTS AS SUMMED FROM COMPONENTS AND AS DERIVED FROM FITTED EQUATIONS
(Bolívares/km at March 1991 values)

VEHICLE TYPE	RESOURCE COST AT INDICATED SPEED					
	10 km/hr	20 km/hr	30 km/hr	40 km/hr	50 km/hr	60 km/hr
Sum of individual costs of tyres, depreciation, spare parts, lubricants, garage labour, and fuel consumption (costs of personal time excluded)						
Private car	8.2926	6.3357	5.6880	5.3755	5.2421	5.1613
Por puesto (car)	7.5256	5.3248	4.6410	4.3968	4.1432	4.0438
Regular-size bus	24.9856	17.9728	15.6650	14.5516	14.0241	13.6751
Minibus	13.7630	10.1669	9.0245	8.5077	8.2532	8.0495
Two-axle gasoline truck	13.5583	9.7828	8.6134	8.0816	7.7726	7.5038
Two-axle diesel truck	15.7417	11.4820	10.1684	9.6018	9.2983	9.0222
Three-axle truck	30.9745	23.1016	20.8412	19.9713	19.3551	18.6634
Truck w. more than three axles	52.6836	37.1705	32.3715	30.3115	29.2981	28.3979
Long-wheelbase jeep	11.7110	8.6315	7.6240	7.1373	6.9228	6.7823
Cost estimates derived from equations presented in the summary section of this paper[a]						
Private car	8.3323	6.2503	5.6792	5.4134	5.2600	5.1602
Por puesto (car)	7.5858	5.2357	4.2670	4.3497	4.1914	4.0891
Regular-size bus	25.2355	17.5545	15.5542	14.6413	14.1194	13.7819
Minibus	13.8383	10.0283	9.0076	8.5359	8.2664	8.0908
Two-axle gasoline truck	13.6678	9.6201	8.5572	8.0708	7.7923	7.6120
Two-axle diesel truck	15.8193	11.3464	10.1566	9.6094	9.2953	9.0916
Three-axle truck	*31.0328*	*23.0336*	*20.8549*	*19.8441*	*19.2613*	*18.8823*
Truck w. more than three axles	53.0023	36.5974	32.3471	30.4108	29.3052	28.5905
Long-wheelbase jeep	11.7940	8.4780	7.5946	7.1880	6.9546	6.8052

[a]It is considered that the fitted equations reproduce the costs obtained via summation of individual components with the required degree of precision. However, they should be used with care for speeds less than 10 km/hr.

APPENDIX

UN MODELO PARA ESTIMAR LOS BENEFICIOS POR REDUCCIONES EN EL TAMAÑO DE FLOTAS DE VEHICULOS COMERCIALES EN LA EVALUACION DE PROYECTOS DE MEJORAS AL TRANSITO O TRANSPORTE URBANO

A. PRESENTACION DEL PROBLEMA

En las áreas urbanas, el tamaño de la flota de vehículos comerciales, particularmente los dedicados al transporte de pasajeros, es determinado por: i) el volumen de pasajeros por trasladar en el período de punta y ii) las condiciones de circulación durante el mismo período. Una mejora al sistema de tránsito, o una ampliación de la capacidad vial, que redujera la congestión durante las horas de punta podría servir para aumentar el número de pasajeros que cada vehículo puede transportar y, por ende, reducir el número de vehículos necesarios.

Normalmente, las evaluaciones económicas de proyectos de tránsito o transporte urbano no consideran los beneficios por reducciones en la flota de vehículos de una manera correcta o congruente. En la presente nota, se presenta un método alternativo para estimar dichos beneficios que se considera tanto sencillo como fácil de aplicar. Sin embargo, se trata esencialmente de una versión preliminar del método y se reconoce que es posible perfeccionarlo, según se indica más adelante.

Mediante el método propuesto, se determina primero el tamaño de la flota necesaria (en ambas condiciones, es decir, sin y con proyecto) y, luego, se estima el valor presente de los recursos necesarios para mantener renovada dicha flota durante el período de evaluación del proyecto o de forma indefinida, según se considere más indicado para el caso. La metodología que se presenta a continuación supone la segunda opción, es decir, se estiman los beneficios por reducción en el tamaño de la flota de forma indefinida. La diferencia entre los valores presentes "sin proyecto" y "con proyecto" representa los beneficios por reducción en el tamaño de la flota a raíz de las mejoras que se analizan.

B. DESCRIPCION DEL MODELO

El modelo usa dos tipos de insumos: i) parámetros básicos de entrada y ii) las salidas de un modelo de simulación del tránsito o transporte. El método de cálculo se resume a continuación:

i) En el caso de vehículos de la locomoción colectiva, la flota de vehículos se estima en base al número de kilómetros recorridos durante la hora de punta y de la velocidad de circulación en el área de estudio, corregido por un factor de ajuste si las rutas son suficientemente cortas como para permitir que un vehículo efectúe más de una ida y vuelta durante esa hora. Este factor también puede ser usado para reconocer, por ejemplo, un porcentaje de la flota en reparación o esperando reparaciones, más bien que en circulación durante la hora de punta. En el caso de los vehículos comerciales de carga, se sugiere estimar el tamaño de la flota simplemente en función del kilometraje y de la velocidad de circulación entre las horas de punta (ecuación 1).

ii) Luego, se estima el kilometraje anual de cada vehículo, de acuerdo con el número de horas de operación por año e informaciones acerca de las velocidades de circulación, tanto durante las horas de punta como durante el resto del día, y dentro y fuera del área de estudio (ecuación 2).

iii) En la próxima etapa se determina la vida promedio del vehículo en años (ecuación 3). Luego, se estima el número de años de vida que le quedan, en promedio, a cada unidad en la flota existente (ecuación 4), lo que indica el momento en que habrá que renovar la unidad representativa. Los cálculos se basan en la suposición de que todos los vehículos tienen la misma edad, lo que obviamente no es efectivo. En una segunda versión, se podría hacer más realista ese componente del método.

iv) Finalmente, se calcula el valor presente de renovar las unidades de la flota en los años posteriores (ecuación 5). Unicamente en el caso "con proyecto" se agrega al valor presente el valor depreciado del número de vehículos liberados, para uso alternativo, por el aumento en las velocidades de circulación (ecuación 6).

C. PRINCIPIOS ALTERNATIVOS PARA LA ESTIMACION DE BENEFICIOS

El modelo cuya aplicación se propone para ciudades venezolanas se describe algebraicamente en las próximas páginas. Cabe acentuar que la metodología para estimar los beneficios está relacionada con el grado de reglamentación del transporte urbano que está vigente en la ciudad cuyo caso se analiza. Tres situaciones posibles se describen a continuación.

i) Transporte público desreglamentado. Se aumentan las velocidades de los vehículos de transporte público, lo que redunda en costos de operación más bajos. Esto los hace más rentables, fomentando así el ingreso al sector de nuevas unidades. Tal situación podría ocurrir en un mercado desreglamentado, en el que los gremios de operadores fueran suficientemente fuertes como para mantener el mismo nivel de tarifas que antes de la implantación del proyecto, a pesar de la reducción en los costos de operación, pero no tan fuertes como para impedir el ingreso de nuevos operadores.

ii) Reglamentación de la cantidad de vehículos de transporte público. Se mejora la productividad de los vehículos, sin que se pueda reducir la cantidad de ellos en operación en cada ruta, aunque el aumento en las velocidades de circulación permitiera ofrecer la misma calidad de servicio que antes con una flota menor. Como consecuencia, la calidad del servicio también mejora.

iii) Transporte público totalmente reglamentado. Las autoridades aprovechan la baja en los costos de operación para rebajar el valor real de las tarifas, lo que podría estimular el movimiento de pasajeros. Podría resultar asimismo en un cambio en el tamaño de la flota.

Cada alternativa implica una manera distinta de calcular los beneficios. La manera propuesta más adelante es una de las más sencillas posibles.

Se pueden desarrollar modelos más refinados basados en el mismo principio básico que el que se describe en la presente nota. Entre los refinamientos que se podrían incorporar en versiones subsiguientes se incluyen: i) suponer una distribución de vehículos según edad; ii) hacer que el número de horas de punta dependa de la implantación del proyecto; iii) hacer que la depreciación no dependa únicamente del kilometraje recorrido; etc.

D. EXPLICACION FORMAL DEL MODELO

1. Parámetros de entrada exógenos al modelo de simulación del tránsito

k_i	Kilometraje de un vehículo de tipo i durante toda su vida operacional.
h_i	Número de horas anuales de utilización de un vehículo de tipo i.
f_{ip}	Proporción del recorrido durante la hora de punta de los vehículos de tipo i que ocurre fuera del área de estudio.
f_{iv}	Proporción del recorrido durante las horas no de punta de los vehículos de tipo i que ocurre fuera del área de estudio.
t_p	Número de horas de punta por día.
t_v	Número de horas no de punta por día.
d	Número de días considerados por año.
c_i	Proporción de la vida de la flota de vehículos de tipo i que ya se ha consumido.
r	Tasa anual de descuento.
$\$_i$	Costo económico de un vehículo nuevo del tipo i.
b_i	Valor residual de un vehículo de tipo i.
z_{ipf}	Velocidad en km/hr de vehículos del tipo i, durante la hora de punta y fuera del área de estudio.
z_{ivf}	Velocidad en km/hr de vehículos del tipo i, durante las horas no de punta y fuera del área de estudio.
$a_i \leq 1.00$	Factor de control, igual a la proporción de los recorridos de vehículos de tipo i que se cumplen en menos de una hora (considerando una ida y vuelta) durante la hora de punta.

2. Informaciones generadas por el modelo de simulación del tránsito

z_{ipd}	Velocidad, en km/hr, de vehículos de tipo i durante la hora de punta, dentro del área de estudio.
z_{ivd}	Velocidad, en km/hr, de vehículos de tipo i en las horas no de punta, dentro del área de estudio.
q_{ip}	Kilometraje de vehículos del tipo i dentro del área durante la hora de punta.
w_i	Depreciación por km recorrido de vehículos del tipo i.

3. Presentación formal de los cálculos para estimar los beneficios por reducción en la flota de vehículos por aumentos en la velocidad de circulación

Los cálculos para los casos "con proyecto" y "sin proyecto" son los mismos, según el procedimiento indicado a continuación, con la sola diferencia de que, en el caso "con proyecto", se agrega como beneficio adicional por la liberación de unidades en el momento de introducir la mejora, el valor representado por la ecuación 6.

Ecuación 1 – Flota de vehículos del tipo i necesaria:

$$FN_i = (1-a_i)\left[\frac{q_{ip}}{z_{ipd}}\right]$$

Ecuación 2 – Kilometraje anual de vehículos del tipo i:

$$M_i = (d)(t_p)\left[(z_{ipd})(1-f_{ip})+(z_{ipf})(f_{ip})\right] + \left[h_i-dt_p\right]\left[z_{ivd}(1-f_{iv})+(z_{ivf})(f_{iv})\right]$$

Ecuación 3 – Vida en años de los vehículos del tipo i:

$$L_i = \frac{k_i}{M_i}$$

Ecuación 4 – Número de años de vida que le permanece, en promedio, a cada unidad de tipo i en la flota existente:

$$E_i = L_i(1-c_i)$$

Ecuación 5 – Valor presente de renovaciones futuras de la flota de vehículos del tipo i:

$$VP_i = (FN_i)\left[\$_i(1-b_i)\right]\left[\sum_{k=0}^{\infty}(1+r)^{-(E_i+kL_i)}\right]$$

Ecuación 6 – En el caso "con proyecto", corresponde descontar del valor presente estimado en ecuación 5, el valor de los autobuses liberados en el momento en que entren en servicio las obras de mejora, que se supone igual a:

$$VPN_i = \left(FN_{i_{\text{“sin proyecto”}}} - FN_{i_{\text{“con proyecto”}}}\right)\left[\$_i - (w_i)(L_i-E_i)(M_i)\right]$$

4. Ejemplo de cálculo

a) Valores hipotéticos de parámetros y otros insumos

Para un caso hipotético en que i = autobús, las variables de entrada pueden asumir los siguientes valores:

k_i	=	1 000 000	$\$_i$	=	US$ 100 000
h_i	=	4 000	b_i	=	15%
f_{ip}	=	0.6	z_{ipf}	=	15 kph
f_{iv}	=	0.6	z_{ivf}	=	25 kph
t_p	=	4	a_i	=	0.05
t_v	=	10	z_{ipd}	=	10 kph
d	=	310	z_{ivd}	=	12.5 kph
c_i	=	0.65	q_{ip}	=	22 500
r	=	10%	w_i	=	US$ 0.085

b) Método de cálculo

1. Se usa la ecuación 1 para calcular el tamaño de la flota de vehículos de tipo *i*:

$$FN_i = (1-0.05)\left[\frac{22\,500}{10}\right] = 2\,113.75$$

2. Se usa la ecuación 2 para calcular el kilometraje anual promedio de los vehículos en la flota:

$$M_i = (310)(4)[(10)(1-0.6)+(15)(0.6)] + [4\,000-(310)(4)][12.5(1-0.6) + (25)(0.6) = 71\,320$$

3. Se calcula la vida útil promedio de los vehículos en la flota mediante la ecuación 3:

$$L_i = \frac{1\,000\,000}{71\,320} = 14.02$$

4. Se calcula la vida útil promedio que todavía les queda a los vehículos del tipo *i* actualmente en circulación, mediante la ecuación 4:

$$E_i = 14.02(1-0.65) = 4.91$$

5. A través de la ecuación 5 se calcula el valor presente de la renovación perpetua de la flota de vehículos de tipo *i*:

$$VP_i = 2\,113.75\,[100\,000\,(1-0.15)]\sum_{k=0}^{\infty}(1.1)^{-(E_i+kL_i)} = US\$\,152\,592\,669$$

Los cálculos presentados se refieren a un caso hipotético. No se ha indicado, hasta este punto, si se trata de un caso "sin proyecto" o "con proyecto", porque ambas series de cálculos son iguales. Sólo difieren los valores de las variables.

Sin embargo, la aplicación de la ecuación 6 se hace únicamente en el caso "con proyecto". Supóngase que i) los cálculos previos se refieren a un caso "sin proyecto" y ii) los correspondientes al caso "con proyecto" (que no se presenta aquí) determinan que $FN_i = 2\,050$. Se puede usar la ecuación 6 para calcular el valor de venta de los vehículos liberados por las mejoras en el sistema de tránsito o transporte urbano, a saber:

$$(2\,113.75-2\,050)[100\,000-(0.085)(14.02-4.91)(71\,320)] = US\$\,2\,854\,302$$

Por lo tanto, si el valor de VP_i en el caso "con proyecto" fuera 145 000 000, los beneficios por reducción en la flota de vehículos de tipo *i* se estimarían en:

$$VPN_i = (152\,592\,669\ -\ 145\,000\,000\ +\ 2\,854\,302) = US\$\,10\,446\,971$$

Los primeros dos componentes de este sumatorio representan los beneficios por no tener que renovar, en años futuros, toda la flota existente antes de implantar el proyecto. El tercero representa el beneficio inmediato por liberar vehículos a raíz de las velocidades más altas permitidas por la implantación del proyecto.