Study of the Transportation Corridor Between Rio de Janeiro, São Paulo, and Campinas

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In this paper the passenger-demand studies and the preliminary economic evaluation of policies to meet the passenger travel demand within the Rio de Janeiro—São Paulo-Campinas Corridor are summarized; particular attention is paid to the introduction of a high-speed train service. Existing methods for travel-demand forecasting were not judged suitable, both because of their cross-elasticity problems and because of the volume of data required to calibrate them. Accordingly, a new direct-demand model was developed centered on a multilevel multinomial-logit mode-split formulation. By applying this methodology, the main results of the evaluation of high-speed train service showed that it is unlikely to be economically justified for the whole corridor. However, it appears to be warranted for part of the corridor—the São Paulo-Campinas link—under all hypotheses adopted.

The 500-km corridor between Rio de Janeiro and São Paulo had in 1975 a population of about 21 million that increases at an annual growth rate of 2.7 percent. For this study, the towns in the corridor were grouped into 12 level-1 zones surrounded by 8 level-2 zones (with 4 million inhabitants in 1975). Four more external zones were considered since they contribute a large amount of freight that goes through the corridor. The entire study was carried out by Promon Engenharia S.A., a Brazilian private consulting company, for the Brazilian Transport Planning Agency (GEIPOT).

This study investigated three policies to meet the travel demand in the area:

1. Transfer of freight from road to rail, which frees the road system for passenger use;
2. Transfer of passengers from road to rail; and
3. Introduction of a high-speed train.

The study was made up of three separate substudies: a passenger-demand study (which included a study of land use within the corridor), a review of available high-speed rail technology (which included estimates of capital and operating costs as well as a route-location study), and a preliminary economic evaluation.

This paper presents only the method used in the transportation studies and in the economic evaluation as well as the results obtained.

METHOD

The aim of the study was to evaluate alternative ways of meeting travel demand within the corridor between Rio de Janeiro, São Paulo, and Campinas. These alternatives included operational measures, such as the partial regulation of freight transport, as well as alternatives that require large capital expenditure, such as a high-speed train (TAV), which would provide a new mode that has characteristics quite different from those of the existing ones.

In addition, the corridor is expected to experience a period of strong population and income growth during the next 20 years, particularly in the Rio de Janeiro-São Paulo section, and it was necessary to take this into account in evaluating the alternatives.

A model was therefore required that was capable of responding to changes in the operational characteristics of existing modes, to the introduction of new modes that had characteristics different from those of the existing ones, and to changes in population and income distribution.

A particularly important requirement was that the model adopted be one in which the demand for travel was responsive to the supply, i.e., that, as the cost and time of travel by various modes changed and as new modes were introduced, both the total volume of travel and the proportions of persons who travel by the various modes respond to such changes. Figure 1 shows the major stages in the modeling process; the demand, supply, and evaluation phases are identified separately.

The modeling approach adopted was therefore one in which a direct-demand submodel is linked with a submodel of the transport network to provide an integrated representation of the transport system in the corridor. It should be noted that, since the demand for travel is a function of the system that satisfies that demand and since the level of service is conversely a function of the demand for travel, the modeling procedure adopted is an interactive one in which the results of the demand submodel are input to the supply submodel, and vice versa, until equilibrium is reached.

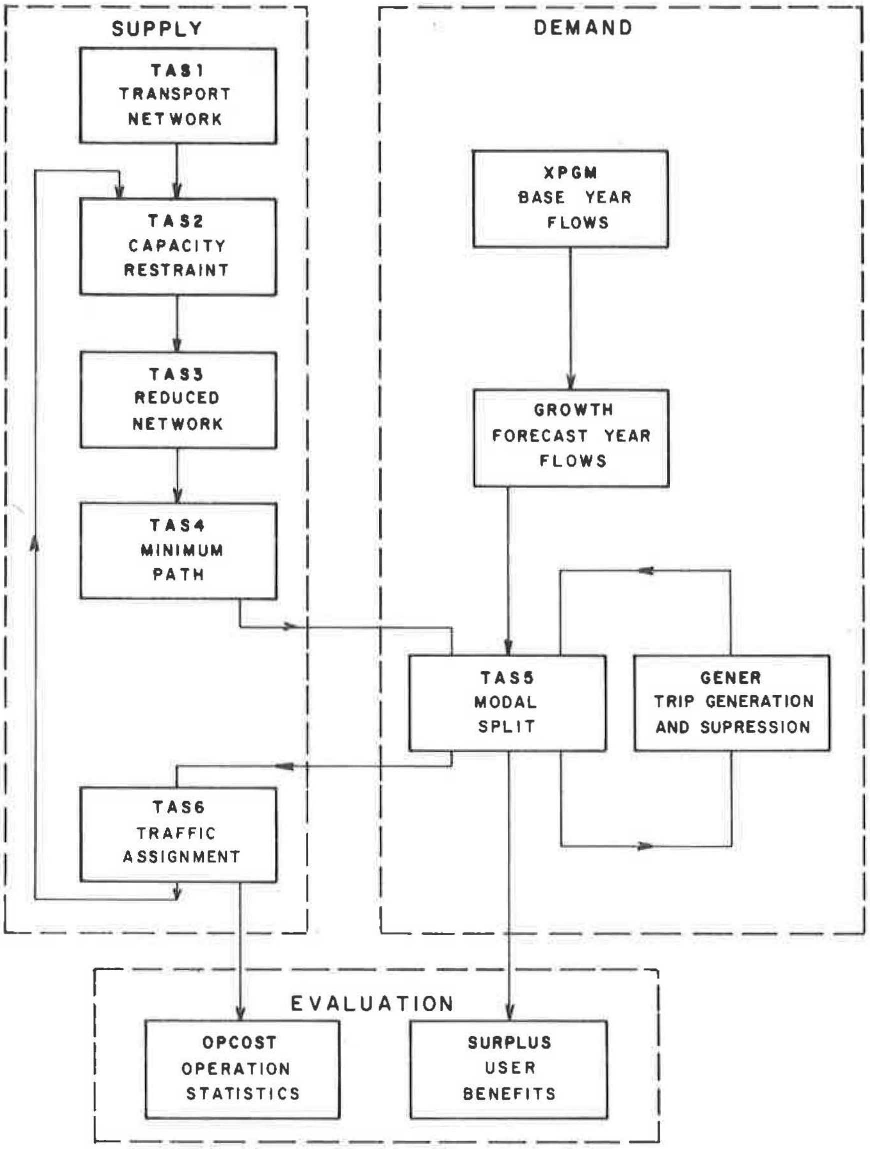
There are several methods available for forecasting the demand for travel. They can be summarized in four main groups: growth factors and allied techniques (Fratar expansion), traditional four-step models, direct-demand models, and disaggregate models.

Each of the above methods was considered for use in the present study. Since the central problem is one of mode split and possible trip generation, it was thought that a technique should be selected that was strong from the point of view of mode split and trip generation. This suggested a direct-demand formulation. However, existing specifications were not judged suitable both because of their cross-elasticity problems and because of the volume of data required to calibrate them (1,2). Accordingly, a new direct-demand model was developed centered on a multilevel multinomial logit mode-split formulation (3,4).

The model used has two important features that distinguish it from earlier direct-demand models. First, the multilevel mode-split formulation allows the clustering of modes into subgroups that contain modes that are relatively close substitutes for each other (4). Second, the linking of mode-split and trip-generation characteristics via the composite utility (U) ensures that cross-elasticities are always positive, if the parameters satisfy certain simple conditions (5).

The supply submodel concerns the transport networks for the various options and years considered in the study. The approach adopted is a conventional one (6): the main steps can be summarized as (a) the construction of a multimode network; (b) the calculation of speeds and times for each link of the network; (c) the extraction of subnetworks (called reduced networks) for each mode; (d) the calculation of minimum paths, costs, and times by mode between all pairs of zones; and (e) the assignment of the flows that are output from the demand submodel to the network constructed above.

Figure 1. Transport model flow chart.



There are two points in this process at which there is interaction with the demand submodel: (a) in the second step, the speeds and times in the network, particularly on the road links, are a function of the amount of traffic and (b) the output of the fourth step, the minimum costs and times, is input to the demand submodel.

The main purpose of an economic evaluation is to provide a measure of the value to society of the different options being considered.

This study has adopted the more-conventional efficiency approach in which individuals provide their own valuation of their costs and benefits. However, it should be pointed out that in a country such as Brazil, in which there are large income differentials both between different parts of the country and different groups in the same region, care is required in comparing different projects since efficiency evaluations inevitably favor those projects that help the richer members of society.

The calculation of the net present value (NPV) of costs and benefits provides the main economic indicator for choice between alternatives. Breakdown of this NPV by user income group and by organization gives useful additional information on the distributional impact of the change. Some other performance indicators may be regarded as useful additional information to be assessed before a decision is reached.

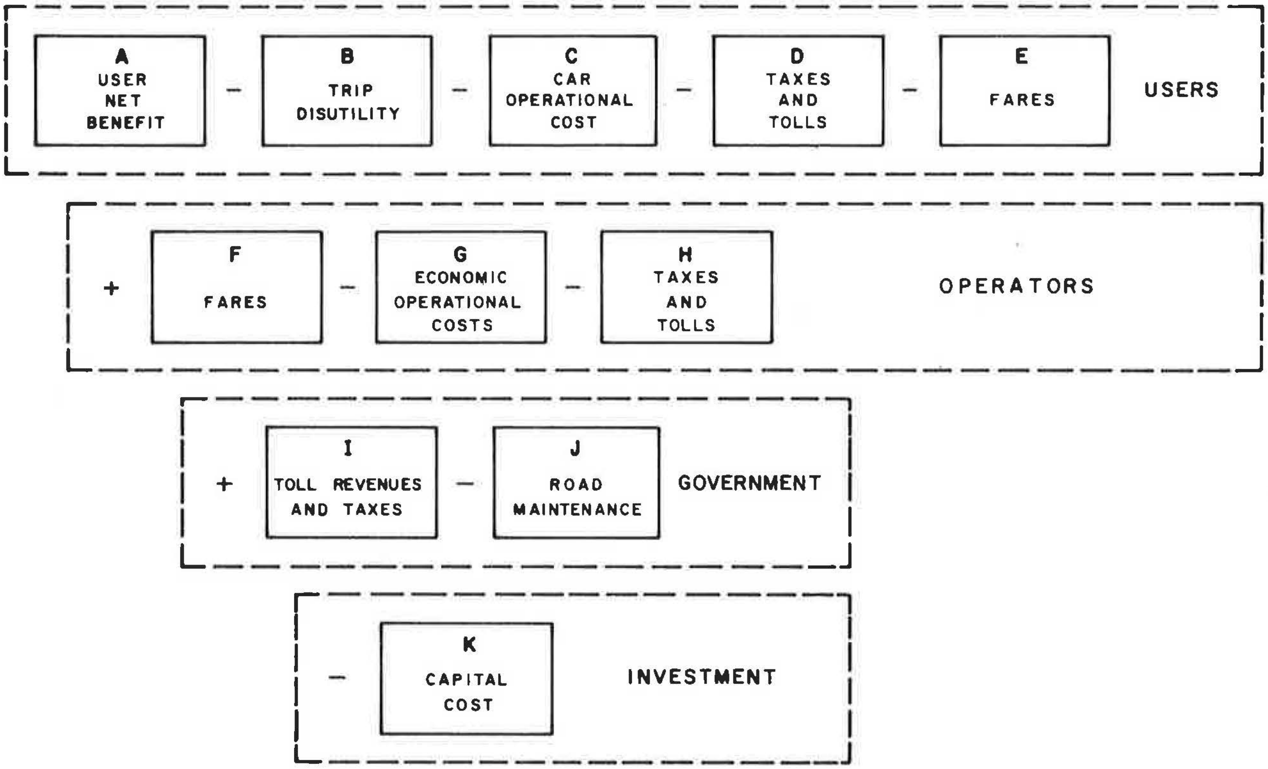
The structure adopted is given in Figure 2, which shows the different categories of costs and benefits (labeled A-K) and their distribution among the three groups--users, transport operators, and government (5). Certain costs and benefits that accrue to a particular group do not accrue to all the groups together.

DEMAND SUBMODEL

Three types of travel demand were identified:

1. Passenger travel among the 20 internal study zones (levels 1 and 2);
2. Freight traffic among the 24 study zones (levels 1, 2, and 3); and
3. The remaining traffic, made up of passenger travel between the study area and the rest of Brazil, as well as all passenger and freight traffic internal to a single study zone. (This traffic was judged to be unaffected by any of the options con-

Figure 2. Economic evaluation structure.



sidered in this study and hence could be treated as constant for any given year.)

The first two groups of demand were estimated by using origin-destination (O-D) models. The third group was estimated on a link basis as the difference between the assigned flows of the first two groups and the average traffic flows recorded on each link.

The study considered total trips subdivided by income group and car ownership, since these are important factors in mode choice, which lies at the heart of the work. In an ideal world, separate models would therefore be estimated for each of the market groups. However, in the present study, information on the income and, to a lesser extent, the car ownership, of travelers was severely limited. It was therefore necessary to estimate models for business and leisure travelers as a whole and to then subdivide the matrices in a manner that was consistent with the aggregate data available.

Based on the above, separate trip models were estimated for

1. Business and nonbusiness trips and
2. Pairs of centers connected by commercial ties (hereafter termed functionally related) and those that are not (hereafter termed unrelated).

The business and nonbusiness models have the same specification in terms of variables, but the specifications are different for functionally related centers and unrelated centers.

A final point concerns the influence of income on trip making, specifically interurban trip making. The results clearly demonstrate the strong influence of income on this type of travel, and it was thus important that this variable be included in the model. However, there were no data available on incomes at the required level of detail, so the model used car ownership instead, which is a good proxy for expenditure on this type of trip over the range of data considered.

The model used for mode split was a multilevel multiple-logit model. Such models are comparatively new; they first appeared in the literature about 1976 (3,7) and are developments of the simple logit model that seeks to recognize the different sensitivities of different travel decisions.

The model used is set within a utility maximization framework, which assumes that each individual associates a utility U_i with each choice i and then makes the choice that has the highest utility (8). In practice, individuals attach different utilities to the same choice, either because they perceive the attributes of the choice in different ways or because they attach different weights to the different attributes. In either case, the utility W_i thus becomes a random variable and may be written (9) as follows: $W_i = U_i + X_i$ (U_i is the measurable utility of choice and X_i is a random variable). The exact form of the choice model depends on the distributions assumed for the random variable. The normal multiple-logit model results if they are assumed to be Weibull (3).

Under this assumption it can be shown that $\mathrm{Var}(W_j - W_i) = \pi^2/3\lambda^2$, where λ is the parameter associated with the Weibull distribution and $\mathrm{Var}(W_j - W_i)$ is the variance of the difference between two choices; however, this will not be the same for all pairs of choices. For example, in the "red-bus, blue-bus" paradox, estimates of the utility of the red bus relative to the blue bus will be almost constant: If passengers like the red bus, they will like the blue bus, and vice versa. Thus, in this situation the variance of the utility differences will be very small and λ should be large. By contrast, in considering car and bus, it does not follow that a particular person's attitude to bus travel can be predicated by his or her attitude toward car travel; in this case the variance will be large and λ should be small.

The formal structure of the mode-choice model used in the study is given below. The model considers five modes: car, bus, conventional rail, air, and TAV.

The model is defined as follows:

$$T_{ijm}{}^{t} = T_{ij}{}^{t} \cdot [\exp(kU_{ij})/\exp(kU_{ij}{}^{0})] \cdot p_{ijm}{}^{t} \tag{1}$$

where

$T_{ijm}{}^{t}$ = number of person trips between i and j by mode m in year t;
U_{ij} = composite utility between i and j for forecast-year network;
$T_{ij}{}^{t}$ = total number of person trips between i and j in year t, assuming the base-year network cost and times, when the composite utility $U_{ij} = U_{ij}{}^{0}$;
$p_{ijm}{}^{t}$ = proportion of trips between i and j by mode m in year t; and
k = calibration constant.

Each of these modes has a utility U_{jk} attached to it defined as follows:

$$U_{jk} = a_{jk} + b_{jk} * g + c_{jk}{}^{1} * t_v + c_{jk}{}^{2} * t_a + c_{jk}{}^{3} * t_w \tag{2}$$

where

U_{jk} = utility of the jth mode for the kth market;
a_{jk} = constant (mode-specific constant),
b_{jk}, $c_{jk}{}^{1}$, $c_{jk}{}^{2}$, $c_{jk}{}^{3}$ = constants that use the same notation as U_{jk},
g = cost,
t_v = time in vehicle,
t_a = access time, and
t_w = wait and transfer time.

Define composite utilities W_1 and W_2 for bus and train and air and TAV (dropping the subscript k) as follows:

$$\begin{aligned}\exp(\lambda_1 W_1) &= \exp(\lambda_1 U_2) + \exp(\lambda_1 U_3)\\ \exp(\lambda_1 W_2) &= \exp(\lambda_2 W_4) + \exp(\lambda_2 W_5)\end{aligned} \tag{3}$$

and define a composite utility U over all modes by

$$\exp(U) = \exp(U_1) + \exp(W_1) + \exp(W_2) \tag{4}$$

Then, if p_m is the probability of choosing mode m,

$$p_1 = \exp(U_1)/\exp(U) \tag{5}$$

$$p_2 = [\exp(W_1)/\exp(U)] \times [\exp(\lambda_1 U_2)/\exp(\lambda_1 W_1)] \tag{6}$$

$$p_3 = [\exp(W_1)/\exp(W)] \times [\exp(\lambda_1 U_3)/\exp(\lambda_1 W_1)] \tag{7}$$

$$p_4 = [\exp(W_2)/\exp(W)] \times [\exp(\lambda_2 U_4)/\exp[\lambda_2 W_2)] \tag{8}$$

$$p_5 = [\exp(W_2)/\exp(W)] \times [\exp(\lambda_2 U_5)/\exp(\lambda_2 W_2)] \tag{9}$$

The model assumed that the choices between bus or train and air or TAV are both second-order decisions compared with the choices among car, bus, or air and thus that both λ_1 and λ_2 were greater than unity. The parameter estimates and comparison of the modeled results with original data are given in Tables 1 and 2.

The term $\exp(kU_{ij})/\exp(kU_{ij}{}^{0})$ in the model generates and suppresses trips according to changes in the composite utility U_{ij}, which is output from the mode-split model. As a function of composite utility it reflects the pure generation effect of changes in the transport network, net of any switching between modes.

The estimates of k that were derivable from the cross-sectional models are approaching or are greater than unity. This confirms the view expressed above that the estimates of k are too large.

However, realistic estimates of k can be obtained by consideration of the following air cost and time elasticities between Rio de Janeiro and São Paulo: business: k = 0.2; nonbusiness: high income, k = 0.3; medium income, k = 0.5, and low income, k = 0.7.

SUPPLY SUBMODEL

The supply submodel represents the networks for the various options and years considered, provides inputs to the demand models, and then assigns the trips that are output from the demand model to the network.

A different network was constructed for each year and each option, although some of the them were physically identical and only different in terms of systems parameters such as operating costs. Four modes (road, bus, train, and air) were used for all runs except those that involved TAV, in which a fifth mode was introduced. However, in order to facilitate the evaluation, the road was split into two submodes--car and truck.

Operating costs were also input to the model at the network-construction stage. These costs are the costs as perceived by the user and hence include perceived motoring costs, fares, tolls, and parking charges.

The selection of minimum paths was handled by using a standard program that identifies the minimum paths between each pair of zones for each mode and calculates the appropriate costs and times. The minimum path was calculated as the path that had the lowest generalized cost. This study considered four groups that had very different values of time and theoretically, therefore, different minimum paths should have been calculated for each group. However, such a process would have been prohibitively expensive in computer time, and it is unlikely that significantly different paths would have emerged from the sparse networks used in the study. The minimum paths were therefore in general calculated by using a value of \$1.35/h (1979 U.S. dollars), as had been used by another study (6).

The study used the all-or-nothing assignment, since the lack of route choice over much of the network meant that the potential improvement from using a probabilistic assignment would be very small. The assignment procedure loaded each of the modes separately into their subnetworks and then recombined them, thus amalgamating all the road flows by the different modes.

ECONOMIC EVALUATION

This study analyzed alternative transport investments in the corridors between Campinas and São Paulo and São Paulo and Rio de Janeiro and the effects that different transport policies might have on the volume of traffic by the various modes. Three options were considered:

1. Transfer of freight from road to rail by using the existing rail system more intensively and thus freeing the road system for passenger use,

Table 1. Parameter estimates for mode-split model.

		Parameter Estimates					Utility	
Market	Mode	Constant	Cost	Time in Vehicle	Access Time	Transfer Time	Rio de Janeiro	Campinas
Business	Car	-0.53	-0.0072	-0.52	-0.52	-0.52	-4.46	-1.72
	Bus	–	-0.0130	-0.36	-0.52	-1.04	-3.42	-1.53
	Train	-0.38	-0.0130	-0.36	-0.52	-1.04	-5.17	-2.26
	Air	-0.78	-0.0130	-0.36	-0.52	-1.04	-3.19	–
Nonbusiness								
High income	Car	1.12	-0.0052	-0.29	-0.29	-0.29	-2.15	0.17
	Bus	–	-0.0130	-0.20	-0.29	-0.57	-2.39	-0.99
	Train	-1.06	-0.0130	-0.20	-0.29	-0.57	-4.24	-2.17
	Air	0.75	-0.0130	-0.20	-0.29	-0.57	-3.69	–
Medium income	Car	0.21	-0.0052	-0.10	-0.10	-0.10	-1.85	-0.32
	Bus	–	-0.0130	-0.07	-0.10	-0.21	-1.24	-0.47
	Train	-0.84	-0.0130	-0.07	-0.10	-0.21	-2.40	-1.34
	Air	-0.26	-0.0130	-0.07	-0.10	-0.21	-4.18	–
Low income	Car	-0.44	-0.0052	-0.04	-0.04	-0.04	-2.07	-0.83
	Bus	–	-0.0130	-0.03	-0.04	-0.08	-0.83	-0.28
	Train	-0.74	-0.0130	-0.03	-0.04	-0.08	-1.72	-1.02
	Air	-1.40	-0.0130	-0.03	-0.04	-0.08	-5.13	–
Global	Car	0.26	-0.0052	-0.22	-0.22	-0.22	-2.58	-0.51
	Bus	–	-0.0130	-0.16	-0.22	-0.44	-1.98	-0.80
	Train	-0.74	-0.0130	-0.16	-0.22	-0.44	-3.34	-1.63
	Air	0.07	-0.0130	-0.16	-0.22	-0.44	-4.10	–

Table 2. Comparison of estimated and modeled flows.

		Flow (thousands of passengers per year)			
		São Paulo-Campinas		São Paulo-Rio de Janeiro	
Market	Mode	Observed	Modeled	Observed	Modeled
Business	Car	747	730	184	187
	Bus	835	801	511	530
	Train	126	177	39	17
	Air	0	0	659	659
	Total	1708	1708	1393	1393
Nonbusiness					
High income[a]	Car	974	959	272	273
	Bus	280	284	208	213
	Train	15	26	11	5
	Air	0	0	58	58
	Total	1269	1269	549	549
Medium income[a]	Car	202	212	57	52
	Bus	181	168	87	89
	Train	27	30	9	11
	Air	0	0	4	5
	Total	410	410	157	157
Low income[a]	Car	6	5	6	4
	Bus	6	7	12	12
	Train	2	2	0	2
	Air	0	0	0	0
	Total	14	14	18	18
Total nonbusiness[b]	Car	1182	1176	336	338
	Bus	800	797	608	611
	Train	148	151	46	40
	Air	0	0	73	74
	Total	2101	2101	1045	1045

[a] Car owners only. [b] Includes those who do not own cars.

2. Transfer of passengers from road to the existing rail system by improving the services offered but without prejudicing the carriage of freight traffic in that system, and
3. Construction of TAV link between Rio, São Paulo, and Campinas.

The study adopted two rates of growth per capita for real income throughout the study period: 2 percent and 4 percent per year. Of these two values, 4 percent per year was selected as the primary forecast for the study, and the TAV option was also examined by using the lower rate of growth.

A per-capita income growth of 4 percent per year was selected as the basic hypothesis on the grounds that, if options proved infeasible for this assumption, the conclusion would also hold under a lower rate of income growth and thus eliminate the need for sensitivity tests. This proved to be the case for both the forced-freight and conventional-train-improvement options.

The main economic evaluation results are presented in Table 3, which presents an approximate evaluation on a sectional basis. The sections are described below:

Section	Length (km)	User Benefits (%)	Passengers per Kilometer (%)
São Paulo-Campinas	93	43	36
São Paulo-Cruzeiro	209	44	43
Cruzeiro-Rio de Janeiro	198	13	21
Total	500	100	100

All costs and benefits in Table 3 are relative to the base case and are expressed in 1979 U.S. dollars discounted to 1990 U.S. dollars at 12 percent per year. The study period extends from 1979 to 2010, giving a 20-year period of operation for TAV if it is opened in 1990.

It shows that under the high-attraction hypothesis, the section from Cruzeiro to Rio de Janeiro does not appear to be viable. Under the low-attraction hypothesis, this conclusion is of course reinforced, and the existence of the Cruzeiro-São Paulo section is also in doubt.

CONCLUSION

Total passengers per kilometer within the study area is forecast to increase from 43.5 million/day in 1975 to 221.1 million/day in 2000. The figures are based on a 4 percent per-capita rate of income growth and on increases in operating costs based on a rise in the price of crude oil to $30/barrel by 2000. The cost increases fall more heavily on some modes than on others, and the limited capital

Table 3. Economic evaluation of hypotheses of attraction.

Section	Costs and Benefits (1979 U.S. $000 000s)			
	Δ(A - B)	Δ(C + G + J)	ΔK^a	Net Benefits
High-Attraction Hypothesis				
São Paulo-Campinas	8 076	783	1028	6 265
São Paulo-Cruzeiro	8 263	936	2310	5 017
Cruzeiro-Rio de Janeiro	2 441	457	2189	-205
Total	18 780	2176	5527	11 077
Low-Attraction Hypothesis				
São Paulo-Campinas	2 875	318	1076	1 481
São Paulo-Cruzeiro	2 942	380	2418	144
Cruzeiro-Rio de Janeiro	869	186	2291	-1 608
Total	6 686	884	5785	17

Note: A, B, C, G, J, and K are as defined in Figure 2.

[a] Data are from Daly and Jachary (7).

expenditure assumed causes traveling speeds on some stretches of road to be comparatively slow by 2000.

Freight transport in the study area is forecast to grow at about 7 percent per year; road freight is forecast to grow more slowly than rail freight. Road freight nevertheless increases at about 6 percent per year throughout the study period. This increase in freight ton kilometers is not translated directly into trucks, since the size of trucks is forecast to increase over the period in which the average payload (including running empty) increases to 10 tons by 2000.

Three broad options were considered in the study, as discussed below.

Transfer of Freight to Rail

The study assumed that under this policy all bulk ores and 10 percent of the general freight would be carried to rail in areas in which a rail link was available. This policy reduces interurban road freight vehicle kilometers by about 20 percent and increases the rail freight on the São Paulo-Barra Mansa link to about 50 million tons/year. Although such a policy is clearly not viable, the results from the transport model show that, even if it were, the impact either on road travel times or on travel demand would be very slight. The study also shows that, even if such a policy were considered from the point of view of pure efficiency, its economic merits depend crucially on the comparative haul costs by road and by rail. The data used in this study suggest that, although rail is more efficient for bulk commodities, road is more efficient for general freight for the typical distance carried within the corridor.

Improvement of Existing Passenger Services

This option was a difficult one to formulate and was eventually modeled in a form that implied a level of frequency, reliability, and punctuality that is competitive with existing bus services. As buses, by their very nature, will always provide a higher frequency of service than the larger-capacity trains, this is a very generous assumption, and the forecasts for this option therefore represent an upper limit. The forecast volume of freight for the link between Rio de Janeiro and São Paulo is such that this policy, like the forced transfer of freight, is not feasible in that corridor. The study has not been able to estimate in detail the effects of such a policy on the São Paulo-Campinas stretch, but it is probable that an augmented service could be incorporated on that link without undue difficulty. However, increasing it to a level competitive with the existing bus service (with, say, 10-min departures in the peaks) would certainly create capacity problems. Although this option shows significant benefits, they are mostly caused by the undefined improvements in the rail service assumed in order to make rail a "bus on rail tracks." Although the study ruled out capital investment, it is clear that very little improvement could be made without at least some injection of capital, and this has not been included in the evaluation. It must be noted that the costs developed for this study indicate that rail passenger services do not cover their avoidable costs, and this option must therefore be considered in that light. The results of the option with a fare level that covered avoidable costs would be much less encouraging.

Introduction of TAV

This option was examined in detail; four fare levels were analyzed in addition to two different assumptions on the attraction of the mode relative to the bus. The results show that TAV gains at the expense of all modes but principally air and bus and that, particularly at the lower fare levels, TAV is also a generator of traffic. The figures hide the very different responses to these changes in the São Paulo-Campinas and São Paulo-Rio de Janeiro corridors. While TAV is competing only with car, train, and bus in the Campinas corridor, it also faces competition from air for the Rio de Janeiro link and thus loses passengers to air as TAV fares approach air fares. Since there are a number of intermediate stations, the volume given for each section of the TAV system is the maximum loading within it. Analysis of these results shows that the fare that maximizes net revenue (i.e., net of variable operating costs) from São Paulo to Rio de Janeiro is about $0.11/km (1979 U.S. dollars) more than the $0.15/km (1979 U.S. dollars) for the remainder of the system. It should be noted that air fares for the year 2000 were forecast to be about $0.15/km (1979 U.S. dollars). In addition to being more sensitive to price, the Rio de Janeiro travelers do not generate the benefits, either per capita or per kilometer, that the remainder of the system generates. This again is due to the fact that TAV competes with air and does not provide a completely new alternative.

The evaluation of this option indicates that it can be divided into three sections for analysis.

1. The Rio de Janeiro-Cruzeiro section is unlikely to be economically justified for many yers, even with a high rate of income growth. The area through which the line passes is in general sparsely settled, and through traffic from São Paulo suffers from competition from air services. In addition, this is the most expensive part of the line to construct, since it contains extensive tunnels and earthworks.
2. The Cruzeiro-São Paulo section (more particularly the Taubaté-São Paulo section) is justified under a high rate of income growth but not under a low one. This section passes through the Paraiba Valley, which is densely settled and has a link with São Paulo that will be severely congested by the end of the century. The ultimate viability of this link would be subject to any future decisions regarding any upgrading of Dutra.
3. The São Paulo-Campinas link appears warranted under both high and low rates of income growth. However, a substantial portion of these benefits

comes from travelers from outside Campinas proper, and this may not be substantiated under closer examination. Nevertheless, the results from both the demand model and the evaluation indicate that this link warrants further examination at a greater level of detail.

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REFERENCES

1. R. Gronau and R. E. Alcaly. The Demand for Abstract Modes: Some Misgivings. Journal of Regional Science, Vol. 9, No. 1, 1969.
2. R. E. Quandt and K. H. Young. Cross-Sectional Travel Demand Models: Estimates and Tests. Journal of Regional Science, Vol. 9, No. 2, 1969.
3. A. J. Daly and S. Jachary. Improved Multiple-Choice Model. In Behavioral Demand Modelling (D. A. Hensher and M. Q. Dalvi, eds.), Heath, Lexington, MA, 1978.
4. H. C. W. L. Williams. On the Formation of Travel-Demand Models and Economic Evaluation Measures of User Benefit. Environment and Planning A, Vol. 9, 1977, pp. 285-344.
5. Promon Engenharia S.A. Estudo Preliminar do Transporte de Passageiros no Eixo Rio de Janeiro-São Paulo-Campinas. In Empresa Brasileira de Planejamento de Transportes. GEIPOT, Brazil, 1979.
6. Sistema de Planejamento de Transportes. Secretaria dos Transportes do Estado de São Paulo, Brazil, 1978.
7. L. B. Lave. The Demand for Intercity Passenger Transportation. Journal of Regional Science, Vol. 12, No. 1, 1972.
8. M. L. Manheim. Fundamentals of Transportation Systems Analysis. Urban Transportation Laboratory, Massachusetts Institute of Technology, Cambridge, 1974.
9. M. E. Ben-Akiva. Structure of Passenger Travel Demand. Massachusetts Institute of Technology, Cambridge, 1973.

Simple Equilibrium Analysis of the Dedication of a Freeway Lane to Exclusive Bus Use

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In this paper, the dedication of an existing freeway lane to exclusive (with-flow) bus use is critically examined. A simple equilibrium analysis by means of a logit mode-choice model and typical volume-delay curves indicates that such projects might bring about the expected benefits only under extreme congestion. The benefits are measured in terms of the ratio of total person hours before to those after the implementation.

One of the many methods suggested in order to increase transit ridership is the dedication of a freeway lane for exclusive use by high-occupancy vehicles or buses. The rationale behind the so-called "diamond lane" is that by shifting the right number of users from private automobiles to buses, everyone would be better off. The automobile users, who are faced with higher congestion on a reduced-capacity freeway (and, it is hoped, who envy the free-flowing buses on the dedicated lane) would shift to transit. Naturally, it is hoped that there would not be a shift of so many users to transit that congestion would develop on the diamond lane. (It is reasonable to assume that the travel time on the diamond lane should be no longer than the travel time on the remaining lanes.)

The above-mentioned scenario seems to be a part of the underlying rationale for several diamond-lane projects throughout the country--for example, the Southeast Expressway in Boston and the Santa Monica Freeway in Los Angeles. In both of these projects no capacity was added to the system, but rather existing automobile lanes were reserved for high-occupancy vehicles. Neither of these projects achieved sufficient diversion to high-occupancy vehicles, possibly because they were terminated at an early stage for other reasons.

Obviously, many local factors, such as enforcement, marketing, and geometric design, have contributed to the early termination of such projects. However, this paper suggests that such projects might not be beneficial even if the flows are allowed to stabilize, due to the equilibrium characteristics of the problem. At the new equilibrium point, the total travel time (in person hours) might be higher than it was before.

The analysis offered here is very simplistic and the actual results in a particular case would naturally depend on the actual demand and congestion functions involved. However, it seems that only under conditions of quite high congestion would benefits be realized.

A detailed analysis of priority lanes had been performed by May and others at the University of California in Berkeley (1-4) by using simulation methods. Such methods can obviously handle many more factors and considerations and (unlike the analysis presented here) are suited for a detailed design or a feasibility study.

Our analysis assumes two modes only (buses and cars) on one freeway segment. It can be extended to additional modes and more-realistic conditions at the expense of somewhat complicating the analysis. With the present scope of the analysis, the reader can follow the formulas and results with the aid of a pocket calculator.

The paper is organized as follows: The next section presents the equilibrium framework and the model from which the total travel time (before and after the implementation of the exclusive lane) can be computed. The performance measure and analysis of