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Measuring the Effectiveness of Priority Schemes for High-Occupancy Vehicles

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In order to measure the effectiveness of high-occupancy-vehicle priority measures or any similar plan to improve transport systems, it is necessary to provide operational definitions of the output of the system and the mobility of its users. Based on theoretical and empirical studies, it is suggested that a useful measurement of system output would be the total distance traveled on the system per day by all travelers (including pedestrians), and a useful measurement of mobility would be the product of daily distance traveled and speed per household and per traveler. These criteria combine the effect of interactions among many travel components such as trip rate, distance, time, and speed that are evaluated separately by the conventional procedures. They can, and often should, be applied to total travel in the area affected, and not only to the direct, local effects of the improvements. The suggested measurements were applied to assess the results of the Singapore Area Licensing Scheme, the first road-pricing measure to be introduced in a complete city center. Data obtained from tabulations prepared in the World Bank from the results of before-and-after household surveys carried out in Singapore in conjunction with the introduction of the Area Licensing Scheme in June 1975 are presented. The results indicate that the introduction of this plan was associated with a significant reduction in both the output of the road system and the mobility of car-owning households and with an insignificant change in the mobility of carless households.

Priority measures for high-occupancy vehicles (HOVs) generally have a number of objectives. The basic ones are likely to be

1. To increase the useful output of the road network and the mobility of the people who use it and
2. To reduce travel costs, with consideration of time, fuel and other vehicle operating costs, accidents, atmospheric pollution, and noise pollution.

It is rarely possible for all objectives to be achieved, and trade-offs have to be accepted; for example, savings in travel costs can be associated with the loss of mobility, and savings in time can be associated with increased accidents. However, many of the concepts routinely used by traffic engineers can be used to assess the achievement of each objective separately. The task of assessing all these effects on the basis of one measuring rod (for example, money) is beyond the scope of this paper, which is concerned with quantitative measurements of transport output and mobility.

LOCAL AND GENERAL EFFECTS

The introduction of HOV-priority measures may be expected to have immediate impacts on traffic along the routes directly affected. For example, the Shirley Highway Express-Bus-on-Freeway Demonstration Project had an immediate effect on bus users when it was introduced and on carpool users when carpools were allowed on the busway. These effects can be assessed with the aid of standard traffic-engineering measurements of vehicle counts, speed, and vehicle occupancy. But the immediate effects can result in significant secondary ones--the encouragement of carpools on the Shirley Highway route can result in a decline in vehicle ownership as travelers who switch to carpools find they need fewer cars in their households. Alternatively, the effect might be that automobiles not used for journeys to work are used by other members of the household, with important consequences to local activities such as shopping. To measure effects of this kind, it is often necessary to consider the total travel habits of a population affected by HOV-priority measures.

Many HOV-priority programs will result in gains to some travelers and in losses to others. It is important that losses as well as gains be considered. In some circumstances it may be desirable to split the travelers affected, e.g., by income group, by mode, by period of travel (peak or off-peak), or by residential zones. Thus, results might show that a program results in gains to bus users and losses to car users, or in gains to city-center dwellers and losses to suburbanites. The appropriate grouping of the affected users will vary from one situation to another. An example that shows gains and losses of mobility in Singapore is given in this paper. The fact that higher-income groups tend to travel more than lower-income groups suggests that mobility is valued at all income levels and that a reduction in mobility is regarded by most as a loss rather than a benefit.

MEASUREMENTS OF TRANSPORT OUTPUT AND MOBILITY

The output of a road network may be expressed in terms of vehicle kilometers (or miles) per unit of time, the vehicles varying in size and shape from the individual pedestrian to the truck or bus. Mobility is a measurement of the movement of the population using the road system. It can be measured in terms of average person trips per day, average person miles per day, or (for each traveler) daily travel distance times speed. More than 30 such definitions exist, ranging from single and simple measures of flow and speed to complex ratings of kinetic energy and various congestion and demand ratios (1).

However, it is suggested that a useful measurement of output, from the users' point of view, is the travelers' daily travel distance, measured in passenger kilometers. This measurement is based on theoretical and empirical considerations, conforms to conventional definitions, and can be derived directly from a home-interview survey without the need to calibrate a model. More specifically, the required data are the observed travel distance per household and per traveler, stratified by mode and by the households' socioeconomic characteristics.

In addition, this paper suggests a quantitative definition of mobility, also based on theoretical considerations and empirical evidence, that is the product of the daily travel distance and the mean speed. Such a measurement follows previous definitions, especially that of travel kinetic energy developed for describing road network levels of service (2), but is extended to encompass the total travel generated per household.

The suggestions presented are exploratory in nature. They need more research, testing, and interaction among professionals and policymakers before the few simple criteria that would meet the varied evaluation requirements of a wide range of travel measures aimed at improving travel conditions can be made final.

MEASUREMENTS OF TRAVEL

Travel Demand

Travel demand is conventionally expressed by many isolated travel components, such as trip rate by purpose, trip distance, and trip time. One major problem in dealing with trip rates is that they depend on the definitions by which trips are linked in the early stages of the analyses. Thus, trip rates may differ not only between one city and another but also within the same city, depending on how they are linked. Furthermore, any change in such trip rates will also change their trip distance and trip time. The total daily travel distance and travel time per traveler and per household, on the other hand, are independent of definition of trip linkage. Moreover, total travel distance is directly related to the amounts that travelers pay in total travel time and total travel money.

The use of total distance traveled simplifies the measurement of travel demand since it is expressed by one unit: daily distance per traveler and per household. Furthermore, the output of a transport system is also measured by passenger and vehicle kilometers of travel, so that the use of this measurement enables demand and supply of passenger transport to have the same common denominator, daily travel distance. Defining travel demand by daily travel distance also facilitates the derivation of a quantitative measurement of mobility described below.

Mobility

Measurements of accessibility usually refer to a locality and express the amount of effort required to reach it. Measurements of mobility, on the other hand, usually refer to households and their travelers, and they should express the amounts of accessibility that travelers can obtain with their resources of trip time and money. In general, a household at a high income level can allow its travelers to achieve a higher level of mobility than can a low-income household. A car-owning household may be expected to have a higher mobility than a carless household, even when both generate the same number of daily trips, since travelers of the former household are able to travel at higher speeds than travelers of the latter.

An operational definition of mobility should express the combined effects of trip rates, distances, and speed; it should also express the potential area that can be reached within a given period of, say, a day. For example, travelers from a car-owning household will generally be able to reach more destinations than travelers from a carless household. The question is, What should the functional form of mobility be?

There are now three independent approaches to research, all of which converge to the following quantitative definition: Mobility equals the product of travel distance and speed during a unit of time (say an hour or a day). This definition is attractive for several reasons. It includes the measurement of travel demand (travel distance, the product of trip rate and trip distance) and is also consistent with measurement of system supply. Therefore, improvements in system supply can be related directly to potential improvements in mobility. This is a simple measurement that can be derived from a few observations available from a home-interview survey. The following is a brief discussion of the three independent approaches.

1. Kinetic energy of traffic flow (2): The level of service of a road network can be measured by

$$L = Cv^2 \tag{1}$$

where

L = level of service of the road network,
C = vehicle concentration (number of vehicles per unit of distance), and
v = observed speed at the given concentration.

This expression is analogous to kinetic energy, namely $(m/2)v^2$, where m is mass. Since traffic flow (q) equals the product of concentration and speed, it follows that Equation 1 can also be expressed as

$$L = qv \tag{2}$$

namely, the product of flow and speed. Thus, the total kinetic energy of all sections of a road network is the sum of the products of travel distance and speed.

2. The alpha relationship (3): Empirical analyses of the interactions between traffic intensity, road density, and speed of various road networks suggested the following relationship:

$$I = \alpha(D/v)^m \tag{3}$$

where

I = traffic intensity (vehicle-km/km^2);
D = road density (lane-km/km^2);
v = space-mean speed (km/h);
m = exponent, found empirically to be 1.0; and
α = coefficient, specific to a road category.

An example of such a relationship is shown in Figure 1 (4). A reordering of Equation 3 results in

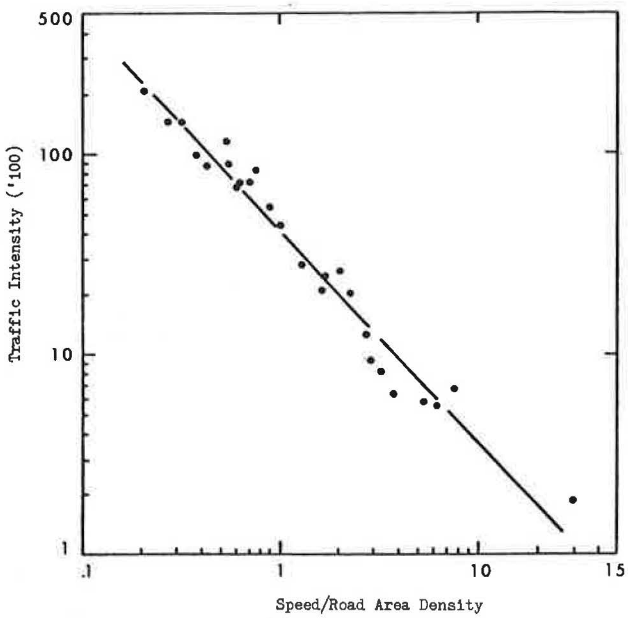
$$\alpha = Iv/D = [(\text{vehicle-km/area}) \div (\text{road length/area})]\ \text{speed} = qv \tag{4}$$

This relationship was called the alpha relationship and was found to equal the observed kinetic energy of the traffic flow, as in Equation 2. Furthermore, the total kinetic energy capacity of the complete road network is the sum of the products of travel distance and speed.

3. Mobility measurements of urban transit systems (5): A mobility measurement for urban transit systems from the users' point of view (based on theoretical considerations of consistency among five basic requirements) was developed for the Urban Mass Transportation Administration in 1972 (5). It resulted in the following expression:

$$M = Pdv \tag{5}$$

Figure 1. Alpha relationship for arterial roads (per 1-m width) in Hagen, Germany.



where

- M = mobility measurement,
- P = number of trips,
- d = average trip distance, and
- v = space-mean speed.

Since the product of P and d equals passenger travel distance, mobility equals the product of travel distance and speed, as in the two previous results.

Measuring Changes in Travel Behavior

Because urban travel is a reflection of activities, it is dynamic in nature and changes daily and hourly. Trying to identify long-term trends of travel behavior from the kaleidoscope of cross-sectional one-day travel patterns is a lengthy and expensive undertaking usually based on a comprehensive home-interview survey. The problem of expense becomes even more acute when the effects of a local change in the transportation system, such as a reserved lane for HOVs, must be assessed, since a comprehensive survey cannot be justified on economic grounds. In such cases, therefore, the surveys are mostly limited to before-and-after counts of vehicles and passengers and measurements of travel time and speed at several key points of the system. The results of such localized observations, however, may not tell the full story of travel behavior, not even of those households directly affected by the change. Consider the case where before-and-after traffic counts of a new HOV-reserved lane show a considerable shift of automobile drivers to carpools and buses. These results could suggest that the measure, as such, was successful: It reduced the cost of travel for the affected automobile drivers. So far, so good. However, a visit to the households in the area may disclose additional effects not directly observable by the localized before-and-after counts, for example: (a) cars remaining at home were used by other household members, thus not necessarily saving gasoline and even increasing traffic flows at other locations; (b) reduced traffic flows and higher speeds along the corridor reduced costs and encouraged carless households to purchase cars and/or encouraged travel from other parts of the system to divert to the improved corridor; or (c) the affected households displayed significantly reduced mobility. Such effects, whether considered good or bad, are integral parts of the same HOV-priority measure and should not be ignored.

The following section details some of the results of a home-interview survey conducted in Singapore before and after the introduction of a major HOV program in the city's central business district (CBD). This example is presented because we were unable to find comprehensive before-and-after data for a major HOV-priority improvement program in the United States.

It should be emphasized that no attempt is made to attribute any results to the HOV program nor to assess whether they are favorable or unfavorable; our purpose is only to suggest that localized traffic counts, or analyses of selected trips, may not convey the whole story. It is also suggested that the analysis and evaluation of HOV-priority programs, especially experimental ones, should encompass all possible effects, so as to reveal those that may be unexpected and unsuspected.

SINGAPORE BEFORE-AND-AFTER STUDY

Background

Following is a summary of travel data collected before and after the introduction of the Area License Scheme (ALS) in Singapore's CBD in June 1975. This measure imposed a fee on each car carrying fewer than four persons that entered a restricted central zone during the morning peak period. The data were derived from conventional before-and-after home-interview surveys, and the household sample was augmented by a sample of car-owning households. The same households were interviewed twice, before and after the introduction of ALS, in order to identify and quantify possible effects on the households' travel behavior.

The first analyses, carried out in the World Bank, were concerned mainly with the direct effects of ALS (6). The present paper reports on the total travel characteristics in the whole area of Singapore, as derived from the before-and-after home-interview surveys.

Four sets of tables were prepared in the World Bank during 1978 and 1979. Travel characteristics per traveler and per household before and after the introduction of ALS and the principal results by household income are summarized in Table 1. Because the original sample was augmented by a survey of car-owning households, it is not representative of the total population and, hence, the tables in this paper are also stratified by car-owning and carless households. Car-owning households are defined as those having the use of a motor vehicle (car or motorcycle) that is based at the household even if it is owned by a firm. Table 2 summarizes the principal travel components, averaged for the whole area.

Trip Rates

The trip rates of car-owning households and of their travelers decreased appreciably, by about 10.5 percent and 5.3 percent, respectively. The difference between the two proportions is the result of a concurrent decrease in the number of travelers per household, as presented in Table 2. The trip rates of carless households and of their travelers, on the other hand, remained practically unchanged.

The trip rates per traveler of car-owning and carless households appear to be very low, just over the minimum of two daily trips per traveler. These low trip rates suggest an underreporting of trips in the home-interview surveys, a recurring problem in such surveys usually corrected by adjustment factors based on screen-line comparisons. No such corrections were made in the Singapore surveys and, therefore, the emphasis in the following analyses is on the relative changes in the travel characteristics, rather than on their absolute values.

Figure 2 shows the relationship between the trip rate per household and per traveler versus household income level for car-owning and carless households. Of special interest is the consistent decrease of the trip rate per household in car-owning households at all income levels, with only a mild decrease in the case of carless households. The trip rate per traveler, on the other hand, remained relatively stable. Thus, most of the variation in the trip rate per household was caused by changes in the number of travelers per household: a decrease of 6.5 percent in car-owning households and an increase of 2.3 percent in carless households.

One possible explanation of the increased number of travelers in carless households is a growth of household incomes, as can be seen in Table 1. Indeed, the average income of carless households increased during the period from S$680 to S$728 (an increase of 7.1 percent), although the average income of car-owning households remained practically the same (S$1380 versus S$1383). As the number of travelers per household tends to increase with income and to decrease with increasing travel costs, it appears that the changes in income levels, coupled with increased car travel costs (because of ALS and a rise in gasoline and parking prices during 1975), resulted in conflicting trends in the number

Table 1. Travel characteristics per traveler and per household.

		Vehicle-Owning Households								Non-Vehicle-Owning Households							
		Household Monthly Income (S$00s)								Household Monthly Income (S$00s)							
Characteristic	Time Period	2-4	4-7	7-10	10-15	15-20	20-25	25+	All	0-2	2-4	4-7	7-10	10-15	15-20	20-25	All
Households	B	57	201	169	236	139	100	172	1074	16	106	171	89	49	20	4	455
	A	55	149	192	259	188	85	146	1074	17	86	159	113	66	14	8	463
Travelers	B	136	612	630	1036	618	473	838	4343	36	257	581	324	232	97	20	1565
	A	129	403	669	971	812	392	678	4054	38	184	521	463	312	64	49	1635
Travelers per household[a]	B	2.39	3.05	3.72	4.34	4.49	4.74	4.86	4.13	2.25	2.38	3.40	3.85	4.74	4.85	5.00	3.44
	A	2.31	2.71	3.50	3.75	4.33	4.61	4.66	3.86	2.23	2.14	3.26	4.10	4.72	4.57	6.12	3.52
Distance per household (km)	B	28.64	42.13	55.47	69.91	76.96	80.10	96.11	66.31	17.17	22.72	38.07	45.07	67.87	70.51	77.83	40.29
	A	22.77	34.15	47.93	59.51	73.19	72.89	79.54	58.22	17.14	19.06	34.70	47.49	67.00	66.51	81.95	40.65
Distance per traveler (km)	B	12.00	13.80	14.91	16.12	17.14	16.90	19.78	16.07	7.63	9.53	11.20	11.71	14.33	14.54	15.57	11.31
	A	9.85	12.62	13.71	15.88	16.92	15.80	17.07	15.07	7.67	8.90	10.65	11.59	14.19	14.55	13.38	11.11
Trip rate per household[a]	B	5.14	6.53	8.11	9.46	10.46	11.28	11.62	9.33	4.50	5.05	7.07	8.05	10.10	10.62	11.75	7.16
	A	4.74	5.77	7.39	7.95	9.27	10.00	10.30	8.26	4.28	4.30	6.62	8.36	9.63	9.28	12.00	7.15
Trip rate per traveler	B	2.15	2.14	2.18	2.18	2.33	2.38	2.39	2.26	2.00	2.12	2.08	2.09	2.13	2.19	2.35	2.08
	A	2.05	2.13	2.11	2.12	2.14	2.17	2.21	2.14	1.92	2.01	2.03	2.04	2.04	2.03	1.96	2.03
Travel time per household (h)	B	2.79	3.81	4.89	5.57	5.63	5.80	6.17	5.25	2.91	3.34	4.41	5.81	7.04	6.88	8.27	4.75
	A	2.70	3.38	4.69	4.83	5.40	5.53	5.27	4.83	2.50	2.57	4.08	5.56	6.36	6.71	9.57	4.61
Travel time per traveler (min)	B	70.07	75.01	78.89	76.95	75.22	73.47	76.15	75.96	77.51	84.13	77.85	90.60	89.11	85.08	99.25	83.01
	A	70.18	74.94	80.39	77.22	74.78	72.19	67.87	74.75	67.30	72.14	75.17	81.38	80.90	88.08	93.78	78.57
Speed[a] (km/h)	B	10.28	11.04	11.34	12.57	13.67	13.80	15.59	12.65	5.91	6.80	8.63	7.75	9.65	10.25	9.41	8.20
	A	8.42	10.10	10.23	12.34	13.58	13.13	15.09	12.06	6.84	7.40	8.50	8.55	10.52	9.91	8.56	8.48
Trip distance[a] (km)	B	5.58	6.45	6.84	7.39	7.36	7.10	8.28	7.11	3.82	4.50	5.38	5.60	6.73	6.64	6.63	5.44
	A	4.80	5.92	6.50	7.49	7.91	7.28	7.72	7.04	3.99	4.43	5.25	5.68	6.96	7.17	6.83	5.47
Trip time[a] (min)	B	32.6	35.1	36.2	35.3	32.3	30.9	31.9	33.6	38.8	39.7	37.4	43.4	41.8	38.9	42.2	39.9
	A	34.2	35.2	38.1	36.4	34.9	33.3	30.7	34.9	35.1	35.9	37.0	39.9	39.7	43.4	47.9	38.7

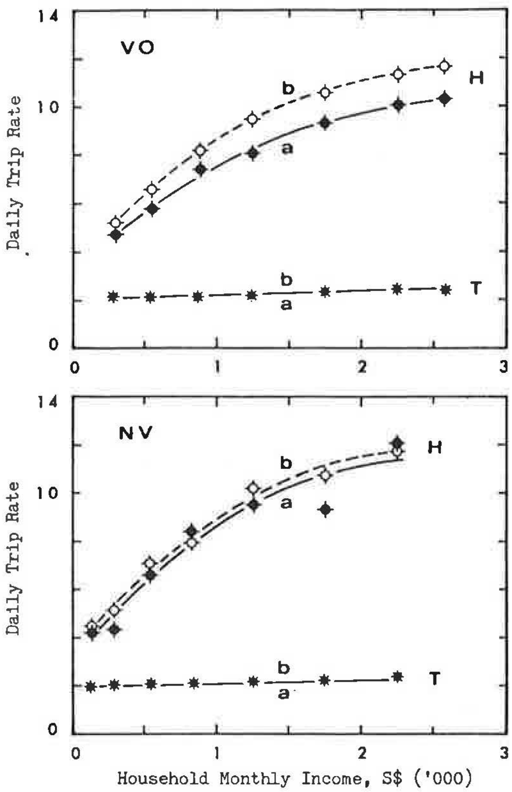
Note: B = before; A = after.

[a]Derived values are weighted by households.

Table 2. Summary of travel characteristics per traveler and per household.

	Vehicle-Owning				Non-Vehicle-Owning			
	Travelers		Households		Travelers		Households	
Characteristic	Before	After	Before	After	Before	After	Before	After
Monthly income (S$)	–	–	1380	1383	–	–	680	728
Travelers per household	–	–	4.13	3.86	–	–	3.44	3.52
Trip rate	2.26	2.14	9.33	8.26	2.08	2.03	7.16	7.15
Travel distance (km)	16.07	15.07	66.31	58.22	11.31	11.11	40.29	40.65
Travel time (h)	1.27	1.25	5.25	4.83	1.38	1.31	4.75	4.61
Speed (km/h)	12.7	12.1	12.7	12.1	8.2	8.5	8.2	8.5
Trip distance (km)	7.11	7.04	7.11	7.04	5.44	5.47	5.44	5.47
Trip time (min)	33.6	34.9	33.6	34.9	39.9	38.7	39.9	38.7
Mobility	209	186	861	720	96	102	336	359

Figure 2. Daily trip rate per traveler and per household by car ownership.



Note: VO = vehicle-owning households; NV = non-vehicle-owning households; H = household; T = traveler; b = before; a = after.

of travelers per household of car-owning and carless households.

Daily Travel Distance

The changes in the daily travel distance per household that took place before and after the introduction of ALS are shown in Figure 3, stratified by household income. The relationships can be expressed by a logarithmic function for car-owning households before:

$$\text{Distance per household} = -141.21 + 29.38\ \ln(\text{income}) \quad (6)$$

and after:

$$\text{Distance per household} = -134.47 + 27.20\ \ln(\text{income}) \quad (7)$$

and for carless households before:

$$\text{Distance per household} = -109.97 + 24.06\ \ln(\text{income}) \quad (8)$$

and after:

$$\text{Distance per household} = -116.78 + 24.98\ \ln(\text{income}) \quad (9)$$

where the daily travel distance per household is expressed in kilometers. The striking result is a significant drop in travel distance per household of car-owning households at all income levels, whereas travel distance remained practically unchanged for carless households.

Table 3 presents the breakdown of the daily travel distance per household by mode used. It shows changes in mode choice within each household group before and after the introduction of ALS. Results of this table can be summarized as follows:

1. The sharp drop in daily travel distance per car-owning household, 12.0 percent, is mainly the result of a decrease in travel by car and motorcycle and, contrary to conventional expectations, no consistent shift to bus travel is noted. Travel distance by walking and bicycle is negligible and is discussed later.
2. Daily travel distance per carless household increased slightly (by only 1.9 percent) and seems to have been the result of a small shift to car and motorcycle travel (probably as passengers), whereas the travel distance by bus decreased.

An assessment of these results indicates that the expectation that ALS would shift travelers from car to transit and raise travel speeds for road users paying the ALS fee was not realized in the observed travel behavior derived from the home-interview surveys. Unfortunately, no transit passenger counts were carried out concurrently with the home-interview surveys to serve as a check on the sampled results.

Trip Distance

An indirect way of checking the above results is to assess changes in trip distance. Table 2 shows that the average trip distance of car-owning households decreased appreciably (from 16.1 km to 15.1 km), whereas the decrease in trip distance of carless households was quite small (from 11.3 km to 11.1 km). This tends to support the assumption that the loss of travel by car-owning households was real.

Another way of checking the above results is shown in Table 4, in which the daily travel distance per traveler is stratified by major trip purposes. It appears that travel distance home by carless drivers remained unchanged and that travel distance to work and business increased slightly. Travel distance of travelers from car-owning households, on the other hand, tended to decrease in the cases of all major trip purposes, thus suggesting once again that the loss of travel distance by such households was real.

Trip Time

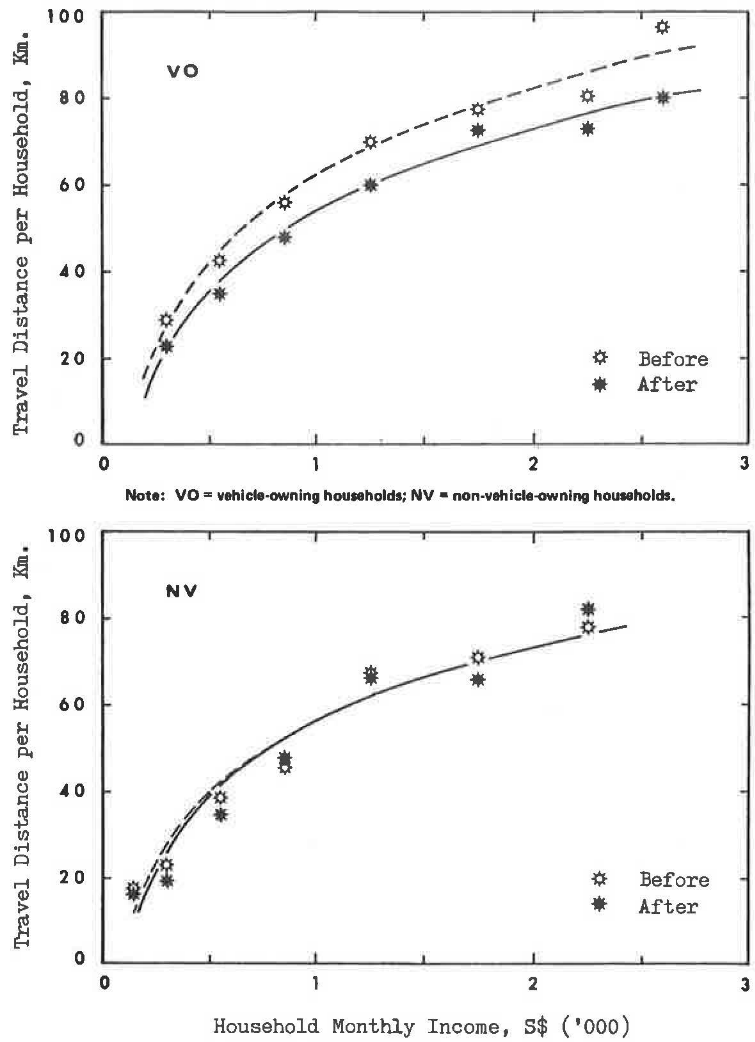
All travel times are door-to-door times, as reported by the respondents in the home-interview surveys. Tables 1 and 2 show that the trip time of car-owning households increased. As the proportion of car travel by car-owning households decreased and the proportion of transit travel increased, the proportion of longer trip times by transit should be expected to increase the average trip time. For carless households (whose total travel remained unchanged) the trip time should not have increased. Indeed, it slightly decreased.

Modal Changes

It is often wrongly assumed that trips can be shifted between modes with no change and that, therefore, such shifts can be expressed as percentages or normalized as probabilities. But Table 3 tells another story, summarized below:

Time Period	Mode	Distance (km)	Share (%)
Before	Car	32.45	49.6
	Motorcycle	6.12	9.3
	Bus	26.93	41.1
	Total	65.50	100.0
After	Car	26.17	45.4
	Motorcycle	4.96	8.6
	Bus	26.49	46.0
	Total	57.62	100.0

Figure 3. Daily travel distance per household by vehicle ownership.



Note: VO = vehicle-owning households; NV = non-vehicle-owning households.

Table 3. Daily travel distance per household by motorized mode.

Time Period	Mode	Distance (km) Household Income (S$00s) 0-2	2-4	4-7	7-10	10-15	15-20	20-25	25+	Avg
Vehicle-Owning Households										
Before	Car	–	4.36	11.21	18.14	29.69	43.33	47.72	66.76	32.45
	Motorcycle	–	11.32	8.66	7.60	5.80	5.12	4.42	2.18	6.12
	Bus	–	12.56	21.08	28.70	33.40	27.86	27.53	26.81	26.93
	Total		28.24	40.95	54.44	68.89	76.31	79.67	95.75	65.50
After	Car	–	2.35	9.33	12.60	25.22	36.32	38.53	51.57	26.17
	Motorcycle	–	8.35	6.43	4.86	5.91	4.59	3.67	1.86	4.96
	Bus	–	11.75	17.80	29.34	27.66	31.94	30.25	25.89	26.49
	Total		22.45	33.56	46.80	58.79	72.85	72.45	79.32	57.62
Non-Vehicle-Owning Households										
Before	Car	–	0.28	2.11	1.48	1.25	11.18	15.64	–	1.91
	Motorcycle	–	0.08	0.27	–	–	–	–	–	0.12
	Bus	14.47	20.37	34.43	41.45	65.40	58.04	59.19	–	36.42
	Total	14.47	20.73	36.81	42.93	66.65	69.22	74.83		38.45
After	Car	0.28	0.45	1.54	5.36	6.49	9.71	2.85	–	3.20
	Motorcycle	–	–	1.09	0.10	1.36	–	–	–	0.59
	Bus	16.15	17.20	30.63	39.80	58.35	56.23	78.43	–	35.39
	Total	16.43	17.65	33.26	45.26	66.20	65.94	81.28		39.18

When modal shares are based on travel distance (as the product of trip rate and trip distance), it becomes obvious that, although the modal share of transit increased from 41.1 percent to 46.0 percent, or an increase of about 12 percent units, the actual travel distance by transit decreased slightly. The reason for this is that, after the introduction of ALS, transit received an increased share of a smaller amount of travel. Furthermore, transit travel distance by carless households decreased in absolute and relative terms.

Daily Travel Time per Traveler

Table 2 indicates that the daily travel time per traveler of car-owning households was virtually unaffected--1.27 h before as opposed to 1.25 h after. One example of the breakdown of daily travel time by mode and by household income level for the before case is shown in Figure 4. It can be seen that, whereas the proportions of time allocated to the different modes varied significantly by household income, the total daily travel time per traveler remained similar at all income levels. This similarity remained also in the after case, although a higher proportion of time was allocated to transit travel.

Trends of daily travel time per traveler of carless households were that

1. Daily travel time decreased slightly, from 1.38 h to 1.31 h;
2. There was more variation between different income groups, probably because of smaller sample size than in the case of car-owning households, although the stable trend is still evident;
3. Proportions of time allocated by mode were different from those of car-owning households, with more of the time allocated to bus travel; and
4. Proportion of time allocated to car travel increased with income even for travelers from carless households.

These trends remain unchanged in the after case.

The results also indicate that time allocated to walking and cycling was a small proportion of total daily travel time per traveler and was similar at all income levels of car-owning and of carless households. The same applied to travel distance by these modes.

Stability and Variation of Daily Travel Time

The stability and similarity of daily travel time per traveler, even after major changes in travel distance by car-owning households, follow trends

Table 4. Daily travel distance per traveler by trip purpose.

	Vehicle-Owning Households		Non-Vehicle-Owning Households	
Trip Purpose	Distance Before (km)	Distance After (km)	Distance Before (km)	Distance After (km)
Home	7.65	7.22	5.42	5.40
Work and business	5.56	5.35	3.47	3.75
School	1.68	1.76	1.64	1.48
Personal and social	1.00	0.62	0.61	0.39
Shopping	0.18	0.12	0.17	0.09
Total	16.07	15.07	11.31	11.11

Figure 4. Daily travel time per traveler by vehicle ownership.

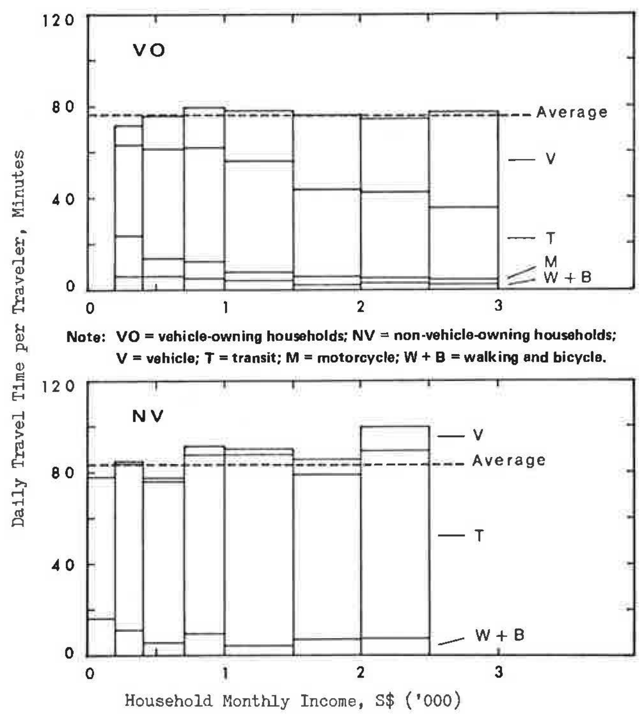


Table 5. Daily travel time per traveler and coefficient of variation by income and vehicle ownership.

	Before						After					
Household Monthly	Vehicle-Owning Households			Non-Vehicle-Owning Households			Vehicle-Owning Households			Non-Vehicle-Owning Households		
Income (S$)	No.	TT (h)	C	No.	TT (h)	C	No.	TT (h)	C	No.	TT (h)	C
Up to 200	9	1.06	0.39	36	1.29	0.40	4	0.54	0.46	38	1.12	0.40
200-400	136	1.17	0.52	257	1.40	0.78	129	1.17	0.50	184	1.21	0.49
400-700	612	1.25	0.58	581	1.30	0.51	403	1.25	0.62	521	1.25	0.52
700-1000	630	1.31	0.74	342	1.51	0.88	669	1.34	0.56	463	1.36	0.54
1000-1500	1036	1.28	0.54	232	1.49	0.73	971	1.29	0.59	312	1.35	0.48
1500-2000	618	1.25	0.54	97	1.42	0.51	812	1.25	0.51	64	1.47	0.48
2000-2500	473	1.23	0.55	20	1.65	0.43	392	1.20	0.51	49	1.56	0.41
2500+	838	1.27	0.64	8	1.26	0.40	678	1.14	0.48	4	2.50	–
Total	4352			1573			4058			1635		
Average		1.27	0.60		1.40	0.70		1.25	0.56		1.31	0.51

Note: TT = daily travel time per traveler; C = coefficent of variation.

already noted in other cities (7,8). Even the higher daily travel time per traveler of carless households versus car-owning households is in line with the previous results in other cities. It may, therefore, be inferred that when travelers are faced with changing travel conditions (e.g., travel costs or speeds) they tend to adjust and fit their choices into a relatively narrow range of average daily travel times.

Stability of daily travel time per traveler does not mean that each and every traveler travels the same amount of time each day. Variations of individual travelers from the mean value can be expressed by the coefficient of variation (standard deviation over the mean). Table 5 summarizes this measurement for the daily travel time per traveler, and it can be seen that it tends to be similar for all segments that have at least 25 travelers. The same range of coefficients was also noted in other cities (4), suggesting that the daily mean travel time per traveler and the variations around it may be a behavioral phenomenon.

Speed

If daily travel time per traveler displays predictable regularities, then the daily travel distance is directly related to travel speed. Although the door-to-door speed in the case of Singapore is a derived value (distance over time), it is still an important indicator for the before and after changes in travel conditions. Table 2 shows that the door-to-door speed of car-owning households decreased slightly, from 12.7 km/h to 12.1 km/h, whereas the speed of carless households increased slightly, from 8.2 km/h to 8.5 km/h.

Two conclusions may be inferred from these results: First, the door-to-door speed of car-owning households is about 50 percent higher than the door-to-door speed of carless households; thus, travelers from carless households have to spend more travel time for less travel distance than do travelers from car-owning households. Second, the before-and-after surveys suggest that a slight deterioration in travel speeds occurred for car-owning households and a parallel improvement of travel speed occurred for carless households. These changes are not necessarily attributable to changes in road-network speeds; the reduction in the door-to-door speed of car-owning households results mainly from a decrease in travel by car and, hence, an increasing proportion of travel by the slower transit mode. Similarly, a shift of travel from transit to car travel may explain the slight increase in speed of carless households. Unfortunately, there were no reported before-and-after speed measurements in Singapore as an independent check on the changes in network speeds.

Mobility

Based on the discussion of mobility above, it is now possible to evaluate the before and after levels of mobility in the Singapore area. A distinction should be made between the mobility per traveler and per household, since the mobility per household may increase as a result of an increase in the number of travelers per household, even if mobility per traveler does not increase.

From Table 6 it can be seen that the mobility of travelers and of households among car-owning households decreased appreciably--by 11 percent and 16 percent, respectively. This can be regarded as a significant loss of mobility. On the other hand, mobility of travelers and of households among carless households increased slightly, by 6 percent and 7 percent, respectively.

It is difficult to assess the effect of these changes on the total population in Singapore directly from the survey results because the sample of car-owning households was augmented and was not representative. An exploratory test based on the proportions of car-owning and carless households at each income level is presented in Table 7. The results suggest that except for the lowest income group, which constitutes about 5.5 percent of all households, the households in each income group experienced a net decrease in mobility, with a total weighted loss of about 12 percent.

Table 6. Mobility per traveler and per household.

Household Income (S$)	Mobility (km^2/h)							
	Vehicle-Owning Households				Non-Vehicle-Owning Households			
	Traveler		Household		Traveler		Household	
	B	A	B	A	B	A	B	A
0-200	–	–	–	–	50	50	100	120
200-400	120	80	290	190	60	70	150	140
400-700	150	130	470	340	100	90	330	290
700-1000	170	140	630	490	90	100	350	410
1000-1500	200	200	880	730	140	150	650	700
1500-2000	230	230	1050	990	150	140	720	660
2000-2500	230	210	1110	960	150	110	730	700
2500+	260	310	1500	1200	–	–	–	–
Average	209	186	861	720	96	102	336	359

Note: B = before; A = after.

Table 7. Total weighted mobility.

Household Income (S$)	Percentage of All Households	Percentage by Vehicle Ownership		Mobility (km^2/h)					
				VO		NV		Weighted Average	
		VO	NV	B	A	B	A	B	A
0-200	5.5	6	94	–	–	100	120	5.5	6.6
200-400	24.5	17	83	290	190	150	140	42.6	36.4
400-700	32.0	33	67	470	340	330	290	120.4	98.1
700-1000	16.0	42	58	630	490	350	410	74.8	71.0
1000-1500	11.0	64	36	880	730	650	700	60.6	56.6
1500-2000	5.5	75	25	1050	990	720	660	53.2	49.9
2000-2500	3.0	87	13	1100	960	730	700	31.6	27.8
2500+	2.5	91	9	1500	1200	–	–	34.1	27.3
Average								422.8	373.7

Note: VO = vehicle-owning households; NV = non-vehicle-owning households; B = before; A = after.

It should be emphasized that all the above results are for the whole Singapore area. Furthermore, the observed changes cannot--and should not--be attributed solely to ALS. Other factors, such as the economic slowdown during 1975, may have caused the observed changes. The point to note, however, is that any anticipated effects of a major change in system supply or policy measures should be analyzed and evaluated within the context of total travel, since the effects may spread to other, possibly unforeseen, parts of travel behavior. To name just one example: The principal justification for improving a road network is the economic benefits of saved travel time by its users. However, since the saved times are often traded off for more travel, forecasts of future travel are found to be underestimates. Thus, analysis of the possible effects of a change in travel conditions should also cover their possible propagation through the whole travel system.

The measurements relating to total daily travel, which are required to monitor travel behavior, either once a year or before and after a major change in travel conditions, can be restricted to a small sample. For instance, travel patterns of one-day cross-sectional data appear to stabilize for groups of travelers numbering 25 or more. Thus, depending on the number of desired stratifications, a sample of several hundred households may often be large enough to provide all required data. In the case of minor changes in travel conditions, measurements of travel behavior could be limited to the households of the travelers directly affected by the program.

It is recommended, therefore, that more attention be given to such small--but continuous--home-interview surveys that, coupled with the standard periodic traffic counts, can provide a reliable basis for the evaluation of such changes in travel behavior as those that result from the introduction of HOV-priority programs.

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Traffic Conflicts Techniques for Use at Intersections

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Field studies and analyses of observation of traffic conflicts at intersections are described. The field studies covered more than 24 sites and used 17 trained observers who applied a number of alternative operational definitions of traffic conflicts. The definitions that provide the best reliability, repeatability, and practicality are recommended. Initial estimates obtained of expected conflict rates as a function of type of intersection are also given.

Traffic accidents are the most direct measure of safety for a highway location. However, attempts to estimate the relative safety of a highway location are usually hampered by the problems of unreliable accident records and the time required to wait for adequate sample sizes. For these reasons, therefore, the Traffic Conflicts Technique (TCT) was developed in an attempt to objectively measure the accident potential of a highway location without having to wait for a suitable accident history to evolve. (Viewed simply, a traffic conflict is a traffic event involving the interaction of two vehicles in which one or both drivers may have to take an evasive action to avoid a collision.)

Most people who have even a fragmentary knowledge of the TCT believe they understand the basic concepts. However, among those who pursue it further, there is a great divergence of opinion, philosophically, about traffic conflict definitions. One school of thought (1) holds that a proper definition of a traffic conflict must ensure that every accident be preceded by a conflict. Although the use of traffic conflicts as accident surrogates is an appealing concept, it can lead to unrealistic data-collection requirements. Also,