Study of Car Travel Characteristics in Singapore

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A survey conducted in 1990 to study the car travel characteristics in Singapore, a city-state with a population of about 3 million, is described. A vehicle-based travel-diary approach was adopted in which the details of all trips made by a sample of 115 cars over an average period of about 4 weeks were collected and analyzed. A total of 11,638 trips were recorded in the survey. Trips were cross-classified and examined by trip purpose, time of travel, and road type. Travel characteristics such as the temporal pattern of car travel, trip duration, trip distance, occupancy level, and trip speed were analyzed, and travel patterns of cars on weekdays and on Saturdays and Sundays were examined. A least-squares fitting technique was applied to provide estimates of journey speeds on different road functional classes. The approach adopted has the advantage that the data offer accurate records of travel by participating cars in actual traffic conditions. The results of the study indicate that the approach could be used as a useful alternative to provide information on car travel characteristics.

Information on travel characteristics of car owners is vital to the planning of transportation systems and formulation of traffic management schemes. Transportation engineers and planners can use such information to analyze existing traffic flow conditions and to evaluate the possible effects of transportation-related policies. Home interview surveys have been a commonly used technique for obtaining relevant data on trip-making characteristics of households, car owners, or adults. The transportation agencies of Singapore have conducted several large-scale household travel surveys in the past 12 years (*1–4*). These household surveys provided useful information on car ownership, distribution of person trips by trip purpose and by mode of travel, and spatial variations in trip patterns.

Certain important travel information—such as vehicle speed by road class and by time of day, trip distribution by road class, and length of trip by road class—is not available from these surveys. Travel speed data are particularly valuable as an indicator parameter of the effectiveness of various traffic management schemes that have been implemented in the island city-state of Singapore. In view of this, a car-travel diary survey was undertaken in 1990 to study the car travel characteristics in Singapore that could not be derived from the earlier household surveys. This paper presents the methodology and results of this study.

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DESIGN OF SURVEY

Basis of Survey Design

A vehicle-based approach was adopted in which the details of all trips made by a sample of 115 cars over an average period of about 4 weeks were collected and analyzed. A major objective of the study was to identify the travel characteristics of survey participants in actual traffic conditions over the study period. Another objective of the overall project, which has been discussed elsewhere (*5*), was to develop automobile fuel consumption models that related fuel consumption to trip length, vehicle speed, and vehicle occupancy level. The use of fuel-purchase cycles was found to be a convenient basis on which to design the survey to meet the requirements of both objectives.

Survey participants were asked to record vehicle usage on a trip-by-trip basis continuously in three consecutive fuel-purchase cycles. Each fuel-purchase cycle was to cover a minimum total travel distance of 300 km (186 mi). For most participants, a cycle could be completed in 1 to 2 weeks. Each participant therefore took 3 to 6 weeks to complete the survey. Each participant was paid S$100 (approximately $60, U.S. dollars), so the project had a budget to engage 120 participants.

The survey was conducted in two phases: Phase 1 ran from January through April 1990, and Phase 2 ran from August through November 1990. Sixty participants of Phase 1 were selected randomly from people working in the National University of Singapore or whose work required visits to the university to ensure close monitoring by the project investigators (i.e., the authors). Besides receiving written survey instructions, every participant in this phase was given a personal briefing by the project investigators. Phase 2 participants were selected randomly from lists of non-university staff recommended by registered commercial companies and Phase 1 participants. Of 60 people selected to participate, 55 completed the survey.

Survey Details

The survey requires considerable effort on the part of participants to record the details of every trip. Great emphasis was therefore placed in the selection of survey participants to ensure that survey data of good quality were returned. It was on this ground that the target population of survey was restricted to car owners who had at least a high-school education and who drove their cars themselves. The study included a

random sample of 115 willing participants. The sample was believed to be representative of the middle-income car owners of Singapore. It is important to note that the participants' day-to-day travel patterns and vehicle use during the period of survey were not affected as a result of participating in the survey.

The following table compares the distribution of engine capacity of the vehicles included in the study with that of the Singapore car population for 1990 (*6*):

Engine Capacity (cm^3)	*Present Study (%)*	*Car Population in Singapore (%)*
Less than 1000	25.2	15.4
1001 to 1600	70.4	65.6
1601 to 2000	4.4	14.7
More than 2001	0.0	4.3

It is seen that cars with engine capacities higher than 1600 cm^3 (98 $in.^3$) were underrepresented and cars with engine capacities smaller than 1000 cm^3 (61 $in.^3$) were overrepresented in the study sample.

Each participant received a book of trip-diary forms and a briefing on how the trip diary should be filled. The trip data to be recorded included the date, the times and odometer readings at the start and the end of each trip, trip purpose, number of adults and children carried, and estimates of the proportions of trip distance by type of road taken. The raw data for each trip were available in the form shown in Figure 1.

Roads were classified into three types: expressways, streets in the central business district (CBD) or satellite residential towns, and other roads not belonging to either of the former types. Specifically, roads classified as "other" refer to major roads and collectors that provide links between satellite towns, between satellite towns and the CBD, and between satellite towns or the CBD and expressways. Three trip purposes were identified: work, business, and miscellaneous. Trips classified as miscellaneous included all trips related neither to work nor to business, such as recreation, social, and shopping trips. Participants were instructed to record the purpose of each using the "to/from" criterion. This simplified representation of trip purpose was adopted as a compromise to reduce the number of data entries in data processing and the number of parameters in the travel speed analysis.

PROCESSING OF SURVEY DATA

A total of 11,638 trips were recorded in the survey. With an average of about 10 data entries per trip, the total number of entries was about 116,000. Considerable time and effort were devoted to data checking and processing. Trip records with missing or illogical data were discarded. The total final number of trip records used in the analysis was 11,589. The relatively low percentage of faulty records was believed to be the result of care taken in survey planning and execution.

Analyses of the data involved cross classifying the number of trips recorded in the survey according to trip purpose, road functional class, and time period of a day. Figure 2 graphically illustrates this method of decomposition of the trip data.

ANALYSIS OF TRAVEL CHARACTERISTICS

The findings of this study pertain to the metropolitan characteristics of Singapore for 1990. Singapore is an island city-state with a land area of 633 km^2. On the basis of the 1990 census (*7*), the population is 2.77 million and the total number of households is approximately 660,000. The average household size is 4.2, and 39 percent of the households are car-owning households. The total car population at the end of 1990 was 272,808, of which 247,808 were household-owned (*6*).

Travel Characteristics by Trip Purpose

Distribution by Trip Purpose

Table 1 presents the proportions of trip by trip purpose. Nearly two-thirds of the trips made by the car owners were for miscellaneous purposes, and about 30 percent were work trips. In terms of person trips, the share of miscellaneous trips increased to 71.6 percent because of higher occupancy levels in such trips.

Table 1 also gives the corresponding proportions of person trips made by car-owning households in Singapore (*4*). Trips by households included trips by public transport such as buses

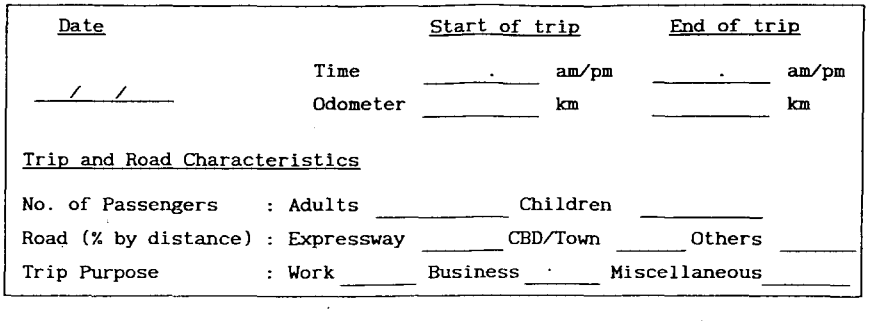

FIGURE 1 Type of data that each survey participant was required to provide for every trip.

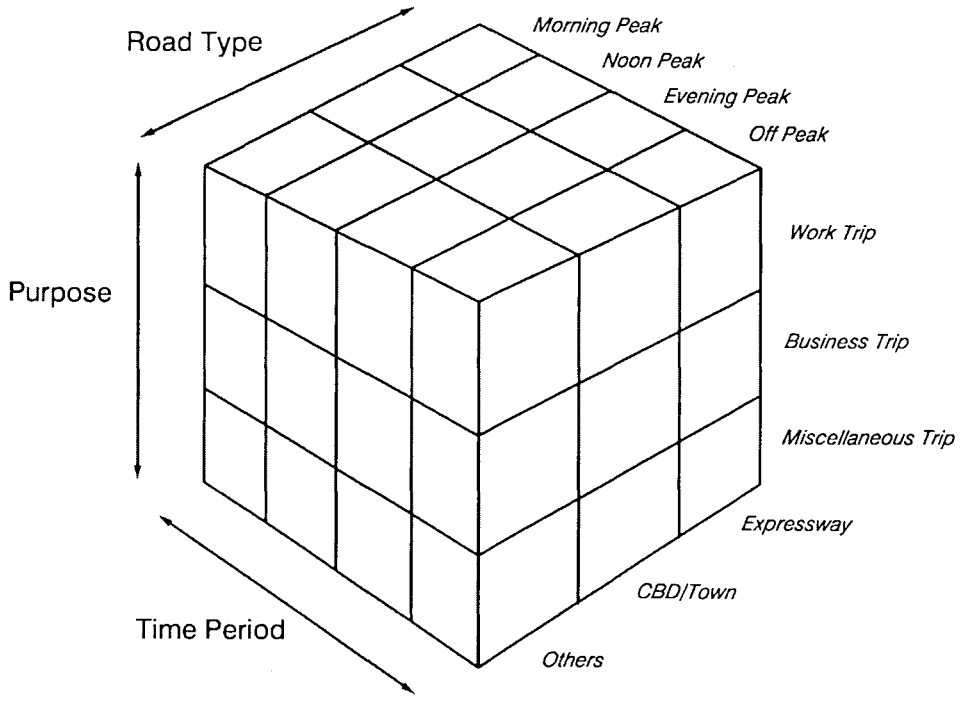

FIGURE 2 Decomposition of trip data.

and rapid mass transit. Comparison of the trip purpose statistics of car owners and car-owning households suggests that a large percentage of the members (including owners of cars) of car-owning households in Singapore did not travel by car to work. The statistics also show that the same was true for business trips. This could be due to several factors unique to Singapore: (a) an area licensing scheme restricts traffic from entering the central city area, (b) the efficient island-wide public transportation system provides a high level of mobility, and (c) Singapore is small in comparison with other major cities, so destinations are easily accessible within reasonable time by most modes of transport.

Time Distribution of Travel

Variations in the times that trips took place were analyzed on the basis of the departure time of each trip. Figure 3 (*top*) plots the distribution of trips by time of day; also shown is the distribution of overall person trips (inclusive of all trips made using different modes of transport). Both distributions exhibit a high morning peak, a slightly lower evening peak, and a much lower noon peak. However, one can also observe the following differences:

1. In the morning, the overall person trips peaked between 6:30 and 8:30 a.m., whereas trips by car peaked later, between 7:30 and 8:30 a.m.
2. For travels by car, the evening after-work peak was followed closely by another peak between 8:00 and 9:00 p.m. This later peak comprised largely miscellaneous trips.
3. The proportion of trips made after 5:00 p.m. was about 46 percent for travel by cars but only about 29 percent for overall person trips.

Most people in Singapore work a half-day on Saturday. This is clearly reflected in Figure 3 (*middle*) by a morning peak between 7:30 and 8:30 a.m. and a higher midday peak between 1:00 and 2:00 p.m. Trips made after 5:00 p.m. still contributed about 40 percent of all trips made by car on Saturday. Figure 3 (*bottom*) shows that there were no pronounced peaking periods on Sunday. Trips were spread evenly between 9:30 a.m. and 9:30 p.m.

On weekdays, the peak-hour car travel in the morning peak period contributed an average of 13.7 percent of total daily

TABLE 1 Distribution of Trips by Trip Purpose

Trip Purpose	Trip Data of Current Study		Person-Trips by Car-Owning Households [4]
	Trips by Car	Person-trips by Car	
Work	28.8%	21.8%	41.5%
Business	8.0%	6.6%	17.9%
Miscellaneous	63.2%	71.6%	40.4%

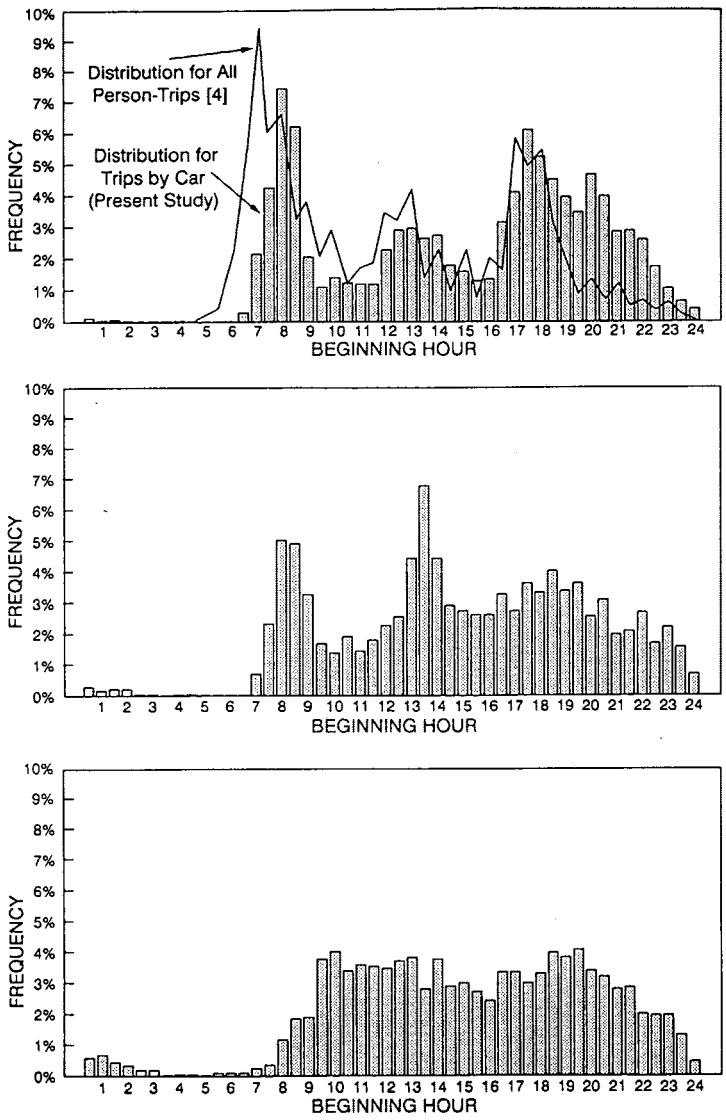

FIGURE 3 Trip distributions by time of day: *top*, time distribution of car travels for weekdays; *middle*, time distribution of car travels for Saturdays; *bottom*, time distribution of car travels for Sundays and public holidays.

car trips. The corresponding percentages for the evening and noon peak periods were 11.5 and 6.1, respectively. On Saturdays, the peak-hour flow in the noon peak period represented 11.2 percent of the daily car trips, and that in the morning peak period had a share of 9.9 percent.

The time distributions of trips by trip purpose are plotted in Figure 4. Figure 4 (*top*) shows that trips to and from work peaked from 7:00 to 9:00 a.m. and 5:30 to 7:30 p.m. Most business trips took place between 11:00 a.m. and 3:00 p.m. It is interesting to see that miscellaneous trips exhibited two peaks: a smaller peak from 12:30 to 2:30 p.m. and a higher and longer-duration peak from 5:30 to 10:30 p.m. The smaller peak coincides with the midday lunch break, whereas the higher peak is probably caused by the after-work social and shopping activities in the evening. Figure 4 (*bottom*) reveals that the morning peak travel was dominated by work trips and the evening peak was caused by both home trips from work and miscellaneous trips. The noon peak was attributed mainly to miscellaneous trips.

Characteristics of Trip Duration

The statistics of trip duration summarized in Table 2 indicate that trips to and from work had the longest mean duration and that miscellaneous trips had the shortest mean duration. This trend is also commonly observed in other major cities in the world (*8,9*). The cumulative curves plotted in Figure 5 demonstrate the same relative magnitude of trip duration by trip purpose. This figure indicates that about 80 percent of car trips were shorter than 30 min. When examined with respect to time of day, Table 2 reveals that trips made during

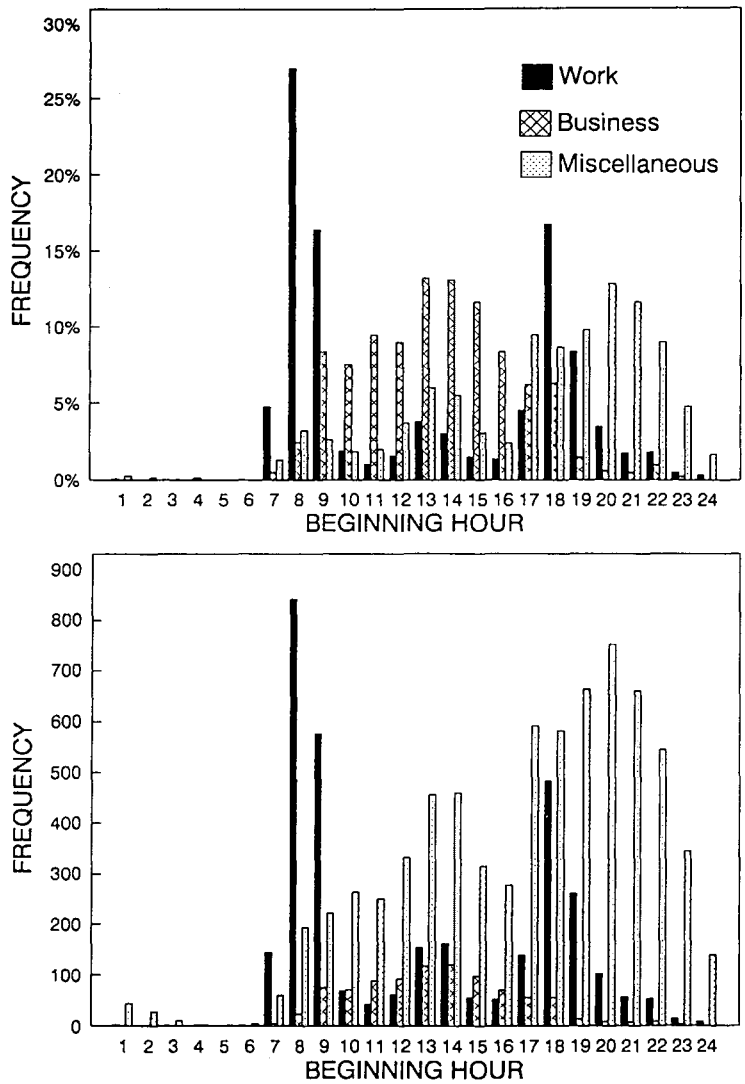

FIGURE 4 Time distributions for weekdays by trip purpose: *top*, by percentage frequency; *bottom*, by trip frequency.

TABLE 2 Variations of Trip Duration with Trip Purpose and Time of Day

	All Trips	Trip Purpose			Time of Day(*)			
		Work	Business	Misc.	Peak 1	Peak 2	Peak 3	Off Peak
Mean (min.)	18.7	21.7	18.6	17.2	22.2	14.6	18.8	18.0
Std Dev (min)	13.5	12.8	13.4	12.7	13.6	11.8	12.1	14.1

Note:(*) Peak 1 = morning peak, 7.00 am to 9.00 am,
peak 2 = noon peak, 12.00 pm to 2.00 pm,
peak 3 = evening peak, 5.30 pm to 7.30 pm.

the morning peak had the longest mean duration, those made during the noon peak had the shortest mean duration, and those made during off-peak periods and the evening peak had mean values about the same as the mean duration for all trips.

Characteristics of Trip Distance

It can be seen from Table 3 that the trends of variation of trip duration with respect to trip purpose and time of day, respectively, as described in the preceding section, also hold for trip distance. That is, by trip purpose, the mean distance covered by trips to and from work was the longest and the mean distance covered by miscellaneous trips was the shortest; by time of a day, trips in the morning peak had the longest mean distance and those in the noon peak had the shortest mean distance. Figure 6 depicts the cumulative distributions of trip distance by trip purpose. It shows that about 80 percent of car trips were shorter than 20 km (12.4 mi).

The variation pattern by trip purpose described above was also observed in U.S. cities, with trip distance ratio of work to all trips varying from 1.34 to 1.54 (*8*). In Table 3 the corresponding ratio for car travels in Singapore is only 1.20. Besides, the mean trip distance of 10.9 km (6.8 mi) is also longer than the range of 4.7 to 9.5 km (2.9 to 5.9 mi) reported for U.S. cities (*8*).

Occupancy Level

Table 4 presents the occupancy levels by trip purpose and by time of day. The overall mean occupancy level of 1.75 is higher than the occupancy levels reported for cities in the United States [between 1.4 and 1.6 (*8*)] and Europe (*8*). The higher car utilization is expected because of lower car ownership and higher car usage costs in Singapore (*10*). Work trips had the lowest mean occupancy level and miscellaneous trips had the highest mean occupancy level, a trend also observed in other cities in the world (*8,9*). Off-peak periods were found to register the highest mean occupancy level because of the presence of a relatively high proportion of miscellaneous trips. Trips made during the morning peak (mostly work trips) had the lowest mean occupancy level.

Characteristics of Trip Speeds

The survey data also allow trip speeds to be analyzed by trip purpose and time of day. Table 5 demonstrates that the overall average trip speed was 32.3 km/hr (20.0 mph), which is in good agreement with the recent estimate of 30 km/hr (18.7 mph) made by the Public Works Department of Singapore (*11*). Work trips had the highest mean trip speed, and miscellaneous trips had the lowest mean trip speed. In general,

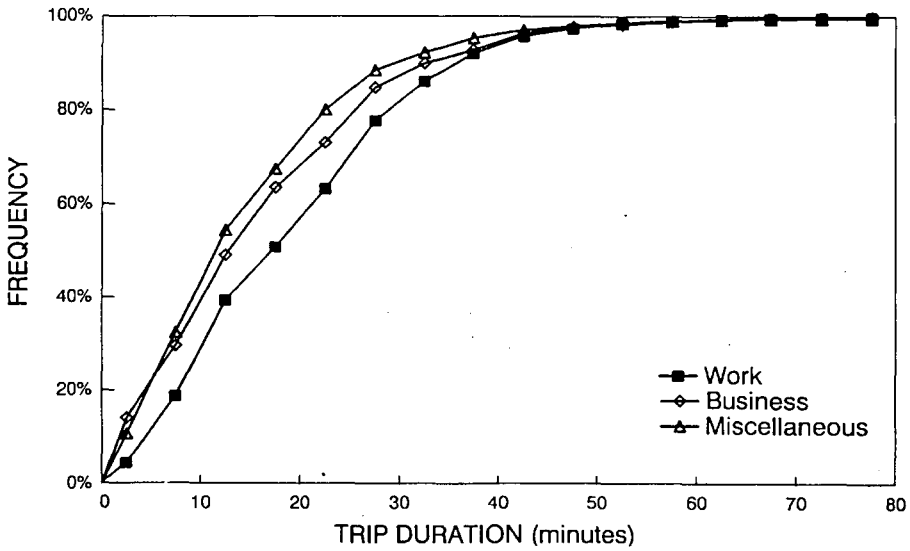

FIGURE 5 Cumulative curves of trip duration by trip purpose.

TABLE 3 Variations of Trip Distance with Trip Purpose and Time of Day

	All Trips	Trip Purpose			Time of Day(*)			
		Work	Business	Misc.	Peak 1	Peak 2	Peak 3	Off Peak
Mean (km)	10.9	13.1	11.1	9.7	13.1	8.3	10.8	10.2
Std Dev (km)	10.5	9.4	9.3	9.6	9.9	8.6	8.9	11.5

Note: (*) Peak 1 = morning peak, 7.00 am to 9.00 am,
peak 2 = noon peak, 12.00 pm to 2.00 pm,
peak 3 = evening peak, 5.30 pm to 7.30 pm.

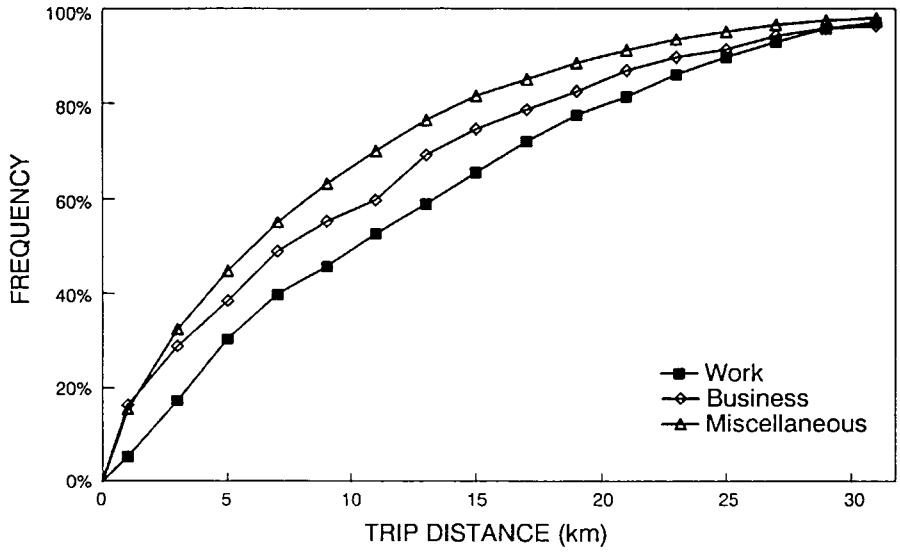

FIGURE 6 Cumulative curves of trip distance by trip purpose.

there was little difference in mean trip speeds among journeys made at different times of day, which could be due to the success of the area licensing scheme that effectively controls the volume of traffic within the CBD during the morning and evening peak periods.

Travel Characteristics by Road Type

Choice of Road Type by Travelers

Most of the trips recorded in the survey covered more than one of the three road types listed in the survey form. Two methods are used to assess the choice of road type by car drivers for their trips: one is to calculate the usage of each road type on the basis of the number of trips that had used it; the other is based on the total distance made on each road type. Table 6 presents the results for both methods of assessment. On the basis of trip usage, about two-thirds of all trips had used the road type "other" in part of the travel, nearly half of all trips covered streets in the CBD or satellite towns, and approximately one-third traveled on expressways. By trip purpose, the same pattern of road use maintained, except that miscellaneous trips differed slightly from the other two trip types by involving more CBD and town streets and fewer expressways.

TABLE 4 Variations of Occupancy Level with Trip Purpose and Time of Day

	All	Trip Purpose			Time of Day(*)			
	Trips	Work	Business	Misc.	Peak 1	Peak 2	Peak 3	Off Peak
Mean	1.75	1.33	1.46	1.98	1.43	1.75	1.52	1.93
Std Dev	1.04	0.60	0.83	1.15	0.69	1.08	0.84	1.15

(*) Peak 1 = morning peak, 7.00 am to 9.00 am,
peak 2 = noon peak, 12.00 pm to 2.00 pm,
peak 3 = evening peak, 5.30 pm to 7.30 pm.

TABLE 5 Variations of Trip Speed with Trip Purpose and Time of Day

	All	Trip Purpose			Time of Day(*)			
	Trips	Work	Business	Misc.	Peak 1	Peak 2	Peak 3	Off Peak
Mean (km/h)	32.3	34.6	33.3	31.1	33.4	30.5	32.4	32.5
Std Dev (km/h)	14.6	13.9	15.5	14.6	14.4	15.3	14.0	14.9

(*) Peak 1 = morning peak, 7.00 am to 9.00 am,
peak 2 = noon peak, 12.00 pm to 2.00 pm,
peak 3 = evening peak, 5.30 pm to 7.30 pm.

TABLE 6 Relative Usage of Road Types by Number of Trips and by Travel Distance

Road Type	Percentage Share in Road Network Mileage	Percentage of Trips That Used the Road Type				Percentage of Total Vehicle-km traveled			
		All Trips	Work Trips	Busin. Trips	Misc. Trips	All Trips	Work Trips	Busin. Trips	Misc. Trips
Express-way	3.8	35.1	40.0	40.9	31.9	40.7	45.8	46.4	36.8
CBD/Town	28.9	46.7	44.6	40.3	48.4	19.6	16.9	19.1	21.2
Others	67.3	66.5	63.6	67.3	67.9	39.7	37.3	34.5	42.0

In terms of distance traveled in vehicle kilometers, expressways and "other" roads had about equal shares of 40 percent each, and CBD and town streets had 19.6 percent. When analyzed by trip purpose, expressways were used most in work and business trips, chalking up about 46 percent in each. On the other hand, the highest percentage of vehicle kilometers traveled (42 percent) for miscellaneous trips took place on "other" roads. Table 6 also indicates that although expressways contributed only 3.8 percent in length to the entire road network of Singapore, they were an important factor in the land transportation system by virtue of the high percentages of traveled distance and trips they attracted.

Derived Characteristics by Road Type

Traveling speed by road type provides useful information on the operating performance of different road types. This information cannot be obtained directly from the survey data because most of the trips covered more than one road type. However, this section shows that the mean journey speed on each road type can be estimated by fitting the survey data to an equation that relates a trip speed to the journey speeds on different road types covered by the trip.

Consider a general case in which a trip covers all three road types considered in the survey. The following information is available from the survey record:

D = total trip distance
d_1 = distance traveled on Road Type 1
d_2 = distance traveled on Road Type 2
d_3 = distance traveled on Road Type 3
T = trip duration

By definition, trip speed V is given by

$$V = D/T \tag{1}$$

Let t_1, t_2, and t_3 be the travel time spent on Road Types 1, 2, and 3, respectively, and

$$\frac{1}{V} = \frac{t_1 + t_2 + t_3}{D} = \frac{t_1}{d_1}\left(\frac{d_1}{D}\right) + \frac{t_2}{d_2}\left(\frac{d_2}{D}\right) + \frac{t_3}{d_3}\left(\frac{d_3}{D}\right) \tag{2}$$

that is,

$$\frac{D}{V} = \frac{1}{v_1}(d_1) + \frac{1}{v_2}(d_2) + \frac{1}{v_3}(d_3) \tag{3}$$

where v_1, v_2, and v_3 are the journey speeds on Road Types 1, 2 and 3, respectively, and the only unknowns in Equation 3.

Since V, D, d_1, d_2, and d_3 are known for every single trip, Equation 3 can be used to estimate the values of v_1, v_2, and v_3 by fitting the 11,589 sets of trip data from the survey records using the method of least squares (*12*). In the current study, the technique of linear regression (*13*) was used to obtain the least-squares estimates for $1/v_1$, $1/v_2$, and $1/v_3$. The dependent variable is D/V, and the independent variables are d_1, d_2, and d_3. The resulting regression expression is

$$D/V = 0.0199(d_1) + 0.0356(d_2) + 0.0234(d_3) \tag{4}$$

The coefficient of determination, R^2, for Equation 4 is .87, and the three coefficient estimates are statistically significant at the 99.9 percent confidence level. The estimates of overall mean journey speed by road type are given by the reciprocals of the coefficient estimates: 50.3 km/hr (31.3 mph) on expressways, 28.1 km/hr (17.5 mph) in the CBD/town, and 42.7 km/hr (26.5 mph) on "other" roads. These estimates are in general agreement with spot speed measurements reported by Singapore road authorities for expressways [ranging from about 40 to 85 km/hr at various times of the day (*14*)] and journey speed measurements for CBD streets [varying between 14.2 and 38.9 km/hr (*15*)].

CONCLUSIONS

This paper describes a study of car travel characteristics in Singapore that was based on travel records of vehicles in actual traffic conditions. The findings obtained from this study are summarized in the following:

- On weekdays, car trips in Singapore peaked from 7:30 to 8:30 a.m., beginning about an hour later than all person trips. A slightly smaller evening peak took place between 5:30 and 6:30 p.m. There was also a small noon peak between 1:00 and 2:00 p.m. The peak hour travel in the three peak periods represented 13.7, 11.5, and 6.1 percent of daily car trips, respectively.
- On weekdays, work trips dominated the trips by car in the morning peak. In the evening peak, there were approximately equal proportions of trips home from work and miscellaneous trips.
- On Saturday, the highest peak occurred between 1:00 and 2:00 p.m. This peak-hour flow provided 11.2 percent of

the daily car trips, compared with 9.9 percent contributed by the peak-hour flow in the morning peak period. No pronounced peaks were observed on Sunday.

- More than 80 percent of car trips were shorter than 30 min. The mean trip duration was 21.7 min for work and 17.2 min for miscellaneous trips. The mean trip duration was longest in the morning peak (22.2 min) and shortest in the noon peak (14.6 min).
- More than 80 percent of car trips were less than 20 km (12.4 mi) in distance traveled. Work trips had the longest mean distance, 13.1 km (8.1 mi), and miscellaneous trips had the shortest mean distance, 9.7 km (6.0 mi). The mean trip distance was longest in the morning peak and shortest in the noon peak.
- The overall mean occupancy level was 1.75. Occupancy level was lowest (1.33) for work trips and highest (1.98) for miscellaneous trips. In terms of time, the morning peak had the lowest occupancy level, 1.43, whereas off-peak periods had the highest level, 1.93.
- Trip speed was highest for work trips and lowest for miscellaneous trips. The mean journey speeds estimated using the least-squares fitting technique were 50.3 km/hr (31.3 mph) for expressways, 28.1 km/hr (17.5 mph) for CBD/town streets, and 42.7 km/hr (26.5 mph) for "other" roads.
- By road type, about 40 percent of vehicle kilometers of car travel were made on expressways and "other" roads; only about 20 percent were made in the CBD/town. In terms of car trips, nearly half involved CBD/town streets, two-thirds involved other roads, and about one-third involved expressways.

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