CAR OWNERSHIP DEMAND AND TRAFFIC CONGESTION IN SINGAPORE'S RESTRICTED ZONE

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abstract: The research in travel demand management in Singapore conducted at the Centre for Transportation Studies (CTS) is reported here. The paper first gives a description of the major car ownership and usage restraints implemented in Singapore. It also reports on the development of a model for forecasting private car ownership, as well as the highlights of an area-wide traffic flow model which may be used to estimate traffic conditions within Singapore's Restricted Zone. The paper concludes with a description of further work in this area at CTS.

1. INTRODUCTION

The city-state of Singapore lies at the southern tip of the Malayan Peninsula, with a total land area of 641.4 sq km, and a population of around 3 million in 1993. About 84% of the population live in high-rise flats, located in self-contained new towns around the island. There are about 2,900 km of paved roads including 112 km of expressways. The vehicle population was about 584,300 (of which 306,200 were cars) at end of 1993. The backbone of the public transport system is the bus. This is complemented by a 67 km long Mass Rapid Transit railway system with three lines running from north to south and east to west along major transport corridors of the island. There is also a large number of taxis operating on the roads.

Singapore has long established the objective of keeping its land transport problems manageable. The Government has pursued with vigour a policy of coordinated land use and transport planning, road network construction, traffic management, and public transport system improvement. But the rapid economic growth over the past two decades has raised the standard of living for the population considerably, resulting in a greater aspiration for people to own and use vehicles. The number of passenger cars per capita has risen nearly 1.6 times from 1974 to 1990. The increase in per capita goods vehicles over this period was even faster. These, coupled with the growth in population, meant there are now many more vehicles demanding the use of road space. This has made it increasingly difficult to keep congestion within manageable levels.

Since Singapore is a small country with 11% of its land already devoted to land transport uses, there is little scope for massive road building without severely disrupting the City's environment. To alleviate this, the Government has plans to construct an underground road network. However, it is an expensive solution and has to be undertaken judiciously. Therefore, travel demand management is included in the land transport strategy to control vehicle ownership and usage, and to strike a balance between demand and supply.

2. TRAVEL DEMAND MANAGEMENT IN SINGAPORE

Singapore has introduced a mixture of ownership and usage restraint measures. To suppress ownership, the Government has imposed high costs on owning vehicles which are all imported as Singapore has no car industry of its own. These consist of high import duties, vehicle registration fees and annual road taxes as well as a Vehicle Quota System (VQS). The usage restraints include a road pricing scheme knows as the Area Licensing Scheme (ALS) and the more common measures of high petrol tax and parking charges. A brief description of the VQS and ALS is given in the following sections.

2.1 Vehicle Quota System

The VQS was introduced in May 1990 to regulate growth of vehicle population. The system applies to all vehicles except scheduled buses and emergency vehicles. Under the system, anyone wishing to own a vehicle must have a Certificate of Entitlement (COE). Vehicles that were already registered at that time were deemed to have a COE. A potential buyer of a new vehicle must first obtain a COE which he can bid for in monthly tender exercises.

The authorities have decided on the vehicle population growth that the road infrastruture can cope with. The present quota is set at a value equal to 3% of the vehicle population plus any replacement vehicles. Thus, the vehicle growth rate is currently 3% a year which is subject to annual review. Vehicles are divided into seven categories. The number of COEs in each category available for bidding is announced every month. Through the open tenders, a person submits a bid on the amount he is willing to pay for the right to own a vehicle. All successful bidders pay the lowest successful bid price.

A COE is valid for 10 years from the date of registration of the new vehicle. At the end of 10 years, the owner is required to renew the COE at its prevailing price if he wishes to continue to operate his vehicle. The prevailing price is set as the 12-month moving average price of the COE in that vehicle category.

2.2 Area Licensing Scheme

The ALS was introduced in June 1975 to a cordoned area known as the Restricted Zone (RZ). The RZ is defined by an imaginary boundary around a 725-hectare area in the city encompassing its most congested parts (see Fig. 1). It is demarcated by 27 overhead gantries at the entry points. During the operating hours (7.30 - 10.15 am on Mondays to Saturdays and 4.30 - 6.30 pm on Mondays to Fridays, at the time of this study), all vehicles except emergency vehicles and scheduled buses, have to purchase and display a valid licence to enter the RZ. Enforcement is by manual supervision at the entry points. Offending vehicles are fined for entering the RZ without a valid licence. Once inside, vehicles are free to move around or leave the RZ.

The ALS has been instrumental in keeping CBD traffic congestion within manageable levels. When first impemented, only the morning period and private cars were under the ALS. The morning inbound private car traffic dropped by about 70% immediately after its

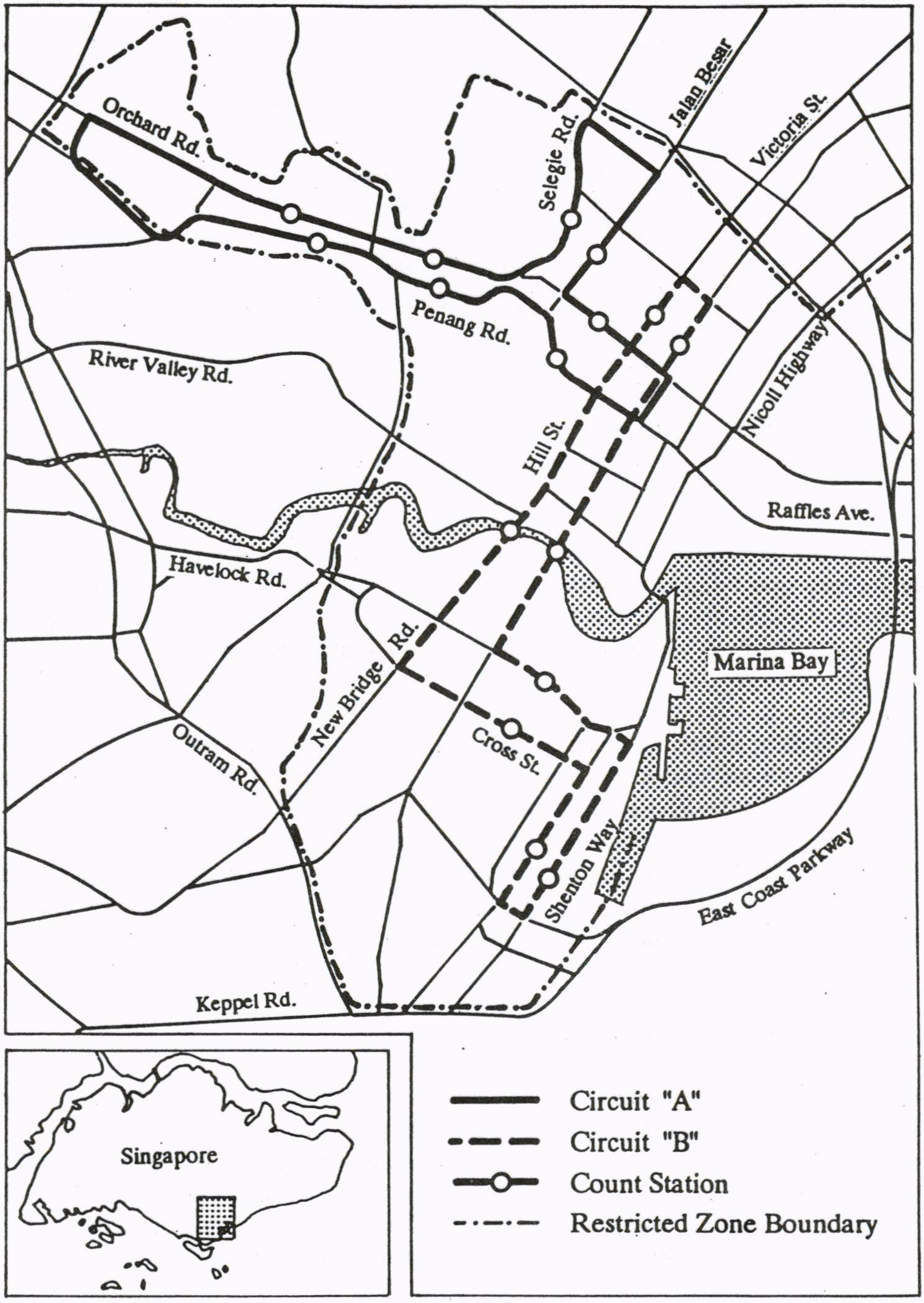

Figure 1 Singapore's Restricted Zone

implementation in 1975 and has remained at or below half of the pre-ALS volume since then, even though car population has doubled over the last 19 years. Inbound traffic of all vehicles also plunged 44% upon implementation of ALS. Total inbound traffic has since crept up but is still below the pre-ALS volume.

In June 1989, area licence fees were imposed on all vehicles (except scheduled buses and emergency vehicles) and the operation period extended to also cover the evening period of 4:30 - 6:30 pm in order to reduce congestion to the work-to-home trips. Due to difficulties in providing alternative routes to outbound traffic which do not wish to pass through the RZ cordon, as well as in enforcement, the evening ALS is also applied to inbound traffic. The introduction of evening ALS resulted in a 44% reduction in total inbound traffic and about 30% reduction in outbound traffic during that period. The drop in the evening outbound traffic occurred even though ALS fees were imposed only on inbound vehicles. This points strongly to a reduction in through traffic during the evening period. In addition, it caused many people to come into the city area after the evening ALS hours which also alleviated congestion in the RZ.

As a result, there was an improvement in traffic conditions within the RZ. For example, the average journey speed during the morning and evening ALS period in 1990 was around 32 kph, or about 7 kph faster than that for the non-ALS period. More details of the ALS and its effects on traffic flow within the RZ can be found in other CTS reports (Menon *et al*, 1992, 1993).

A further refinement to the ALS was implemented in January 1994 -- vehicles entering the RZ between 10:15 am and 4:30 pm on weekdays and from 10:15 am to 3:00 pm on Saturdays also need to purchase and display an area licence, which is charged at a lower fee than the regular one. The purpose of this refinement is to combat congested traffic conditions inside the RZ during the non-ALS hours, especially the surges in inbound traffic immediately before and after the ALS periods; and also to pave the way for the planned implementation of an Electronic Road Pricing system in 1997.

2.3 CTS Research In Travel Demand Management

Research in demand management at the Centre for Transportation Studies (CTS) of Nanyang Technological University, focuses on control of congestion within the RZ and implications on the limits on car ownership growth. To address these issues, models for estimating traffic conditions within the RZ and car ownership demand are required. In addition, there is a need to understand the effects of road pricing on travel demand, as well as the relationship, if any, between car ownership and congestion in the RZ.

If one is able to predict the likely traffic conditions (measured by average travel time or traffic speed) within the RZ for various volumes of traffic in it, then one could establish the desired traffic volume in the RZ corresponding to a pre-defined acceptable level of traffic conditions. If one also knows the effect of road pricing on travel demand, then it would be possible to charge the appropriate fee such that traffic in the RZ would be at the level corresponding to the desired traffic conditions.

It was mentioned earlier that vehicle growth rate in Singapore is currently set at 3% a year.

The Government has indicated that this would be relaxed after the Electronic Road Pricing (ERP) Scheme is in place. To be able to estimate an allowable vehicle growth rate, it is useful to have some knowledge of any relationship which exists between car ownership and congestion in the RZ, and the demand for car ownership.

This paper presents the research work in this area that have been completed to date. Namely, the highlights of an area-wide traffic flow model for estimating average traffic speeds in the RZ, as well as the modelling of private car ownership demand in Singapore.

3. AREA-WIDE TRAFFIC FLOW MODEL FOR THE RZ

Most studies of traffic flow relationship deal with uninterrupted flow on a single link of freeways or expressways. The methodology for developing area-wide (such as the RZ) models is not well established. Little has been done in this area around the world. Smeed (1966, 1968) was the first to develop an area-wide model. He used theoretical analysis to relate the number of vehicles entering an area per unit time with the average traffic speed, total land area under study and the fraction of that area used for roads. Smeed compared data from several cities with his model and concluded that field observations seem to follow reasonably well with his theoretical predictions.

Zehavi (1972) used an "alpha relationship" which hypothesizes that the average speed within a study area is proportional to road density and inversely proportional to total vehicle-kilometres of travel in the area per unit time. Ohta *et al* (1989, 1992) also used this approach and developed aggregate models for Japanese cities using the same variables. However, demand was measured in vehicle-kilometres of travel per day, hence the temporal variations in flow and speed were not reflected.

Williams *et al* (1987) and Mahmassani *et al* (1990) conducted microscopic traffic flow experiments using network simulation. They concluded that the fundamental traffic flow relationship among flow Q, speed V, and density K holds also at the network level, i.e.

$$Q = V\,K \tag{1}$$

None of these aggregate speed-flow models is directly applicable to a situation where traffic speed changes reflecting changes in link or cordon flows are required. Traffic counts at the RZ cordon are regularly conducted by the Public Works Department, Singapore (PWD), and it was preferable to relate traffic speed with these counts for application purposes. CTS developed a model which relates traffic speed with traffic volume crossing the RZ cordon. The following section highlights the CTS study and the resulting speed-flow model for estimating travel times associated with traffic in the RZ. Details of this model may be found elsewhere (Fan *et al*, 1991).

3.1 CTS Traffic Speed-Flow Study For the RZ

Due to the size of the RZ, the CTS study used traffic flows along two major travel corridors to represent the general traffic conditions inside the RZ. Route A passes through the commercial and retail areas within the RZ, with 31 signalised junctions over a length of 7.2 km. Route B is 6.7 km long with 32 intersections and covers the major financial and service centres. These two routes (see Figure 1) covered most of the major roads inside the RZ and could be considered as representative.

Journey time survey was conducted for three days using a fleet of ten test cars. The time of stopping, starting and crossing the stopline at each intersection was recorded. In order to get representative journey time data, test car drivers were instructed to drive at the speed of a randomly chosen car in front. Classified counts of inbound and outbound traffic were also carried out at all entry and exit points along the RZ boundary, and at another 16 stations located at strategic points along the circuits.

The following relationship between average journey speed V and average density K in the RZ was developed. Figure 2 shows the plot of this model and the data points.

$$V = 42.08 \exp(-0.0833\ K^{0.64}) \qquad (R^2 = 0.92) \qquad (2)$$

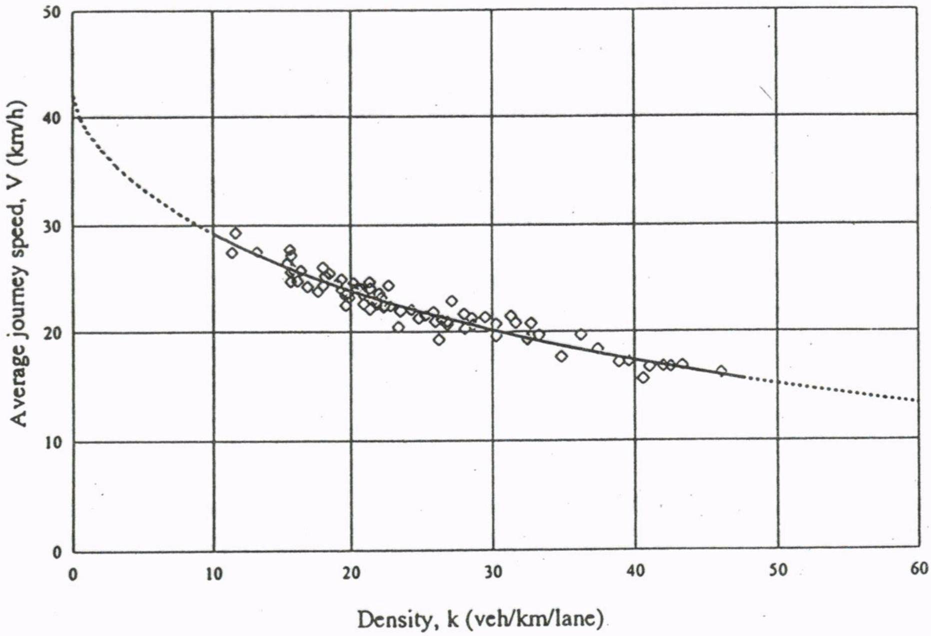

Figure 2 Relationship Between Average Journey Speed and Density in the RZ

Equations (1) and (2) are then used to derive a model relating traffic speed and average lane volume Q_w which is given below:

$$Q_w = V(44.9 - 12\ ln\ V)^{1.563} \qquad (3)$$

As mentioned earlier, a model relating traffic speed with the RZ cordon counts is preferred for application purposes. The CTS study revealed a very strong correlation between average lane flow and the total inbound and outbound flows Q_{IO} across the RZ cordon. This is given below and shown in Figure 3.

$$Q_w = 26.31 + 0.0124\, Q_{IO} \qquad (R^2 = 0.95) \qquad (4)$$

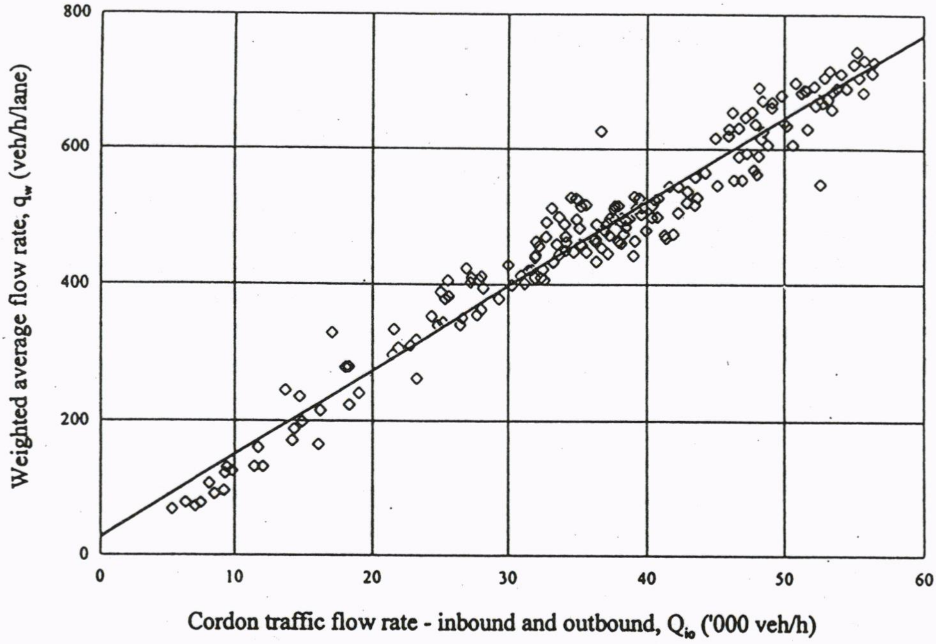

Figure 3 Weighted Average Lane Flow Rate V Inbound and Outbound Flow Rate

The final area-wide traffic flow model for the RZ using the total cordon flow was then obtained by combining Equations (3) and (4):

$$Q_{IO} = 80.645\, V\, (44.9 - 12\, ln\, V)^{1.563} - 2122 \qquad (5)$$

4. PRIVATE CAR OWNERSHIP DEMAND

A report by the Organisation for Economic Co-operation and Development (OECD 1982) provided a good summary on past modelling of car ownership in Europe. In general, two types of models have been used to forecast car ownership in the past. The first is a cross-sectional type model relating car ownership levels with household characteristics such as household size, occupation, etc. Such models require substantial amounts of data and analysis. The second is of the time series type which extrapolates historical trends into the future. The earlier forms used time as the explanatory variable. Recent research have introduced the use of gross domestic product and socio-economic variables such as income as explanatory variables.

The OECD report identified household type (size and income), occupation of head of the household, residence location, accessibility to public transport, and gross domestic product as factors having significant effects on car ownership in Europe.

4.1 Private Car Ownership Demand in Singapore

To model the growth trend of private cars in Singapore, data from 1976 to 1989, the period between the implementation of the ALS and implementation of the VQS, are used. From 1990 onwards, the growth in vehicles has been set at 3% per annum by the Government and is therefore not suitable for inclusion. The explanatory variables initially used in model development included: (a) population of residents of age 25 to 59, (b) real gross domestic product (RGDP), (c) annual road tax, (d) car price and (e) fuel cost. It was found that RGDP was the most reliable factor for explaining variations in private car ownership in Singapore over this period. Table 1 shows the number of private cars, resident population and real gross domestic product (in 1985 prices) for the years 1976 to 1989.

Table 1 Historical Data on Private Cars, Population, and Real Gross Domestic Product

Year	Private Cars	Population (millions)	RGDP (S$millions) in 1985 prices
1976	135,499	2.293	19,880.6
1977	134,903	2.325	21,781.6
1978	137,240	2.354	24,046.0
1979	143,402	2.384	26,284.7
1980	152,574	2.414	28,832.5
1981	161,692	2.443	31,603.1
1982	179,635	2.472	33,772.3
1983	202,092	2.502	36,537.2
1984	217,119	2.529	39,572.5
1985	221,279	2.558	38,923.5
1986	220,566	2.586	39,641.4
1987	222,487	2.613	43,371.8
1988	237,801	2.647	48,203.4
1989	257,371	2.685	52,657.4
Source: Registry of Vehicles, Department of Statistics			

As can be seen from the Table, per capita RGDP in Singapore went up nearly 2.26 times from $8,670 in 1976 to $19,610 in 1989. An increase of 6.48% per annum. The number of private cars has risen 1.9 times over the same period, or an annual growth rate of 5.06%. On a per capita basis, private cars has increased 1.63 times -- from 0.059 (one for 16.9 persons) to 0.096 (one for 10.4 persons) over these years.

Using the data in Table 1, the following model was developed:

$$\underset{(15.7)}{\text{CAR} = 40501 + 4.2396\ \text{RGDP}} \qquad (R^2 = 0.953) \qquad (6)$$

where CAR is the private car population, and
RGDP is real gross domestic product (S$ millions in 1985 prices).

In Eq. (6), the number in parentheses under the coefficient associated with RGDP gives the t-statistic for that coefficient. One can see that both the values of R-squared and t-statistic indicated a strong relationship exists between private car ownership and RGDP. The good fit provided by the model to historical data is also illustrated by the plot of actual and modelled private car population over this period (see Figure 4).

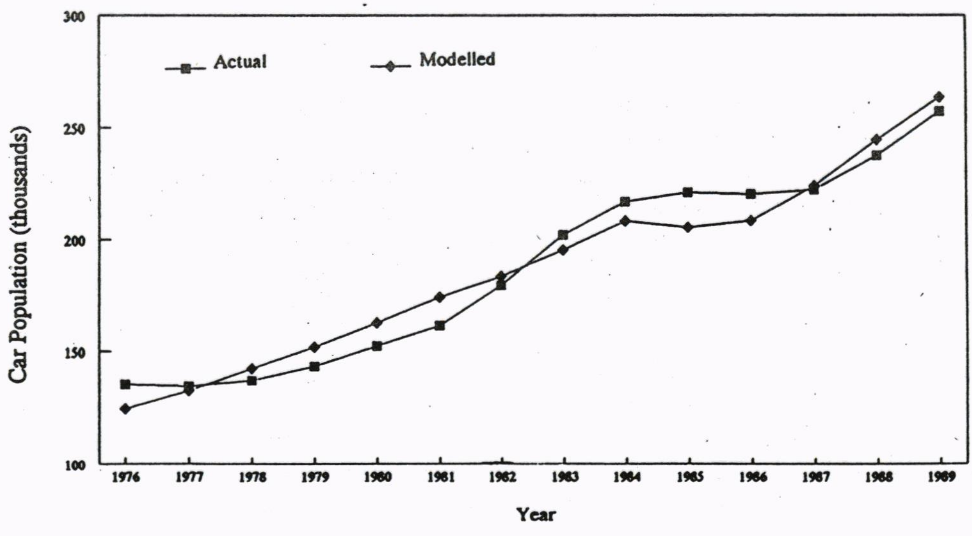

Figure 4 Actual and Modelled Private Car Population

It is noted that in 1993, the real gross domestic product of Singapore was $71,211.9 million (in 1985 prices) and the number of private cars stood at 306,216. Using the model in Eq. (6), the number of private cars in 1993 would have been around 342,400 if the Vehicle Quota Scheme were not implemented. Thus, one may infer that implementation of the quota scheme resulted in a reduction of some 36,200 in the growth of private cars between 1990 and 1993, or 11.8% less compared to the actual number of private cars in 1993.

Looking at this from another angle, one may say that there is an unsatisfied demand for 36,200 private cars in 1993. This would be a useful piece of information for policy makers, particularly when revising the allowable annual vehicle growth rate after the ERP system is in place.

5. CURRENT AND FUTURE RESEARCH

This paper has presented some of the research in congestion control and demand management conducted at CTS. Specifically, the basic tools for estimating demand for private car ownership, and for predicting congestion within the CBD of Singapore corresponding to various levels of traffic in it have been developed.

To promote effective demand management and congestion control in Singapore, further research is planned by CTS in two areas. Firstly, research has started on investigating the relationship between private car population growth in Singapore and trips to the RZ. If indeed there is a relationship, then estimates of traffic congestion within the RZ caused by increases in car population may be obtained using the area-wide traffic flow model described earlier in Section 3.1. This would then provide some insights into the allowable car ownership levels in order to keep congestion within the RZ manageable.

Past studies on car ownership and usage were theoretical in nature, and the study of usage was on average annual distances travelled by cars. To the author's knowledge, there has not been any study which relates car ownership and traffic congestion levels. This is probably due to the difficulty involved in such a study, as there is no obvious relationship between the two. There is some indication from surveys in Singapore that car-owning households tend to make more trips, but whether this leads to traffic congestion would clearly depend on when and where the trips are made.

However, there are relatively few popular destinations in a small place like Singapore, and the area in and around the RZ has been a major focus for congestion management. Therefore, it may be possible to identify a relationship between car ownership and congestion within the RZ. Given the difficulty mentioned above, the focus of the current research on this is confined to investigating congestion within the RZ during the commute period.

The second study to start in the near future will be aimed at understanding the effects of road pricing on travel in general, and traffic volume entering the RZ in particular. The objective is to develop a model which would allow the setting of charges for the use of road space in order to keep traffic volume at acceptable levels. If the modelling effort is successful, it will enhance the effectiveness of the ERP system which is to be implemented sometime in 1997 or 1998.

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