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An advanced demand management instrument in urban transport

Electronic road pricing in Singapore

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Road pricing is a demand management instrument that has been effectively used in Singapore to help alleviate traffic congestion beginning with the Area Licensing Scheme (ALS) in 1975 and, subsequently, the Electronic Road Pricing (ERP) system in 1998. The paper discusses the level of motorisation in the city-state, the traffic problems faced and the development of the ERP system. The operational and technical features of the system, its impacts, advantages and limitations are then carefully examined. Valuable lessons are drawn on how to successfully implement an electronic road pricing system. © 2000 Elsevier Science Ltd. All rights reserved

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Introduction

Singapore, an island city-state with a land area of 647.8 km^2 and a population of 3.1 million in 1997, is a very densely populated city with over 4700 persons per km^2, a density which is one of the highest in the world. The island, which lies 137 km north of the equator, faces a severe constraint of land scarcity. In 1997, the total built-up area in Singapore totalled 322.2 km^2, which is a huge 49.7% of its total land area. Road infrastructure occupied some 11.0% of the total land area.

Despite its physical constraints, Singapore has climbed rapidly from being a developing country with a GNP per capita income of US$800 in 1965 to a newly industrialising economy in 1997 with an estimated GNP per capita income of US$26 475, a figure which ranks highly among Asian countries. In 1997, the transport and communications sector of the economy contributed a significant 11.1% of GDP, employed some 210 000 people and absorbed 18.1% of annual consumer expenditure.

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Singapore's land transport policy

Singapore has prospered from its excellent air and sea communication links with the outside world. Since it gained independence in 1965, the government has realised that the value of its strategic location as a regional hub could be severely compromised by traffic congestion problems. In the early 1970s, the first comprehensive transportation study completed by Wilber Smith and Associates (1974) highlighted the danger of uncontrolled private car ownership and usage in the context of Singapore's limited land resources. This key study helped shape the key element of Singapore's land transport policy that has remained till today: reducing traffic congestion. The alleviation of traffic congestion was and is still seen as invaluable in helping to make Singapore an attractive destination for foreign investment, trade and tourism. The main land transport strategies which were formulated on the basis of this policy are (LTA, 1996):

(1) integrated and coordinated land use and transportation planning so as to minimise travel demand and maximise use of road space;
(2) expanding the road network, maximising its capacity and providing accessibility to all parts of the city;

(3) improving the efficiency of the public transport system and integrating rail, bus and taxi services;
(4) effective travel demand management by managing vehicle ownership and usage;
(5) improving traffic management measures.

Prior to 1995, the management and administration of the transport sector in Singapore was fragmented and run by several transport-related agencies. The task is now handled by a single amalgamated agency called the Land Transport Authority (LTA).

Traffic congestion and road pricing

In the demand management of urban transport, the main objective of which is to alleviate traffic congestion and improve traffic flow efficiency, various policy instruments such as economic instruments, regulatory measures and physical restraints can be used. Road pricing is an economic instrument which directly affects the cost of road usage while there are more indirect ones such as taxes and charges which are levied on vehicle ownership and parking. In road pricing, externalities such as congestion, accidents and pollution can be internalised by imposing charges on road users.

Road pricing is traditionally acknowledged by economists as a first-best solution or benchmark for containing externalities and optimizing traffic flow (Verhoef, 1996). Alternative approaches such as more indirect economic instruments (road taxes, parking fees, etc.), regulatory measures (parking regulations, land use controls, etc.) and physical restraints (traffic cells, traffic collars, etc.) vary in their degree of efficiency in dealing with externalities depending on how closely they meet the ideal economic criteria of charging vehicles according to their amount of contribution to congestion at a particular place and time. Although less efficient than road pricing, these alternative approaches may however be socially and politically more feasible and thus may be more commonly implemented.

A simple and manual road pricing instrument is area licensing, which is a scheme where a permit must be purchased to take a vehicle into a designated urban area during peak traffic hours. Economists view it as a form of traffic congestion tax while transport planners see it as a type of cordon pricing which charges motorists who enter a cordoned-off area.

Singapore's manual road pricing system, the Area Licensing Scheme (ALS), has been highlighted by Foo (1997) as a key factor in earning Singapore its reputation as one of the most efficient urban transport systems in the world. The ALS is one of a range of demand management instruments used in the city-state where the need for managing urban transport demand is of utmost significance since there are limits to road network expansion in a small island such as Singapore.

The predecessor: the Area Licensing Scheme (ALS)

Table 1 shows that from 1961 to 1970, private car population in Singapore doubled from 70 108 to 142 568. Traffic density in terms of number of vehicles per km of public roads rose from 82.1 to 149.9. By 1975, cars represented half of Singapore's total vehicle population and traffic congestion problems started to appear in the CBD. It was found that average travel speed had fallen to around 20 km h^{-1} (Toh, 1992, p 290). Apart from tightening price restraints on vehicle ownership, for instance by raising taxes on vehicles, the government introduced an innovation called the Area Licensing Scheme (ALS) in June 1975.

Under the ALS (Fig. 1) a permit must be purchased to take a vehicle into a designated "Restricted Zone" during peak traffic periods. The ALS was used together with more conventional usage restraint measures such as high petrol taxes and high parking charges. In 1975, motorists driving cars and taxis had to purchase a daily license of S$3 (or S$60/month) to enter the restricted zone from 7.30 am to 10.15 am from Monday to Saturday.[1] No charges need to be paid for off-peak hours, Sundays and other public holidays.

The boundaries of the ALS were located within the Central Area of Singapore (which contained the CBD). The cordon covered an area of over 7 km^2 and included almost all of the roads in the Central Area. Soon after its introduction, rush-hour traffic was reduced by 45%, traffic speeds increased by 20% and accidents fell by 25% (UNCHS, 1995, p 35).

In 1991, it was found that the number of vehicles entering the restricted zone during the morning peak period was 46 000 compared with over 74 000 in March 1975, just before the ALS was implemented (Yap, 1993, p 41). This is a remarkable feat considering the 93.4% growth in vehicle population and 45.9% rise in traffic density during the 1975–1990 period (see Table 1). An extensive discussion of the ALS and its impacts can be found in Foo (1997).

Though the ALS was successful in curbing traffic congestion in the Central Area by restraining traffic flow volumes during peak hours, it did not curb vehicle population growth. Nor did price restraints in the form of deterrent taxes such as high import duties and registration fees deter vehicle purchases. In the 1975–1990 period, vehicle population and traffic density in Singapore increased by 93.4% and 45.9%, respectively. In 1990, faced with the long term prospects of rising traffic volumes and increased congestion, the government imposed a quantity or quota

[1]More than two decades later, under the 1998 set of charges and prior to the conversion to the ERP system, licenses for private cars remained at S$3 per vehicle and were valid for use from 7.30 a.m. to 6.30 p.m. on Mondays to Fridays and 7.30 a.m. to 3.00 p.m. on Saturdays.

Table 1 Vehicle population in Singapore and related indicators (1961–1995)

Year	Private cars[a]	Other vehicles	Total no. of vehicles	Vehicles km^{-1} of road	No. of persons/car
1961	70 108 (−50.6)[b]	47 828 (−65.4)	117 936 (−57.9)	82.1	24.3
1970	142 568 (0.4)	147 855 (6.9)	290 423 (3.6)	149.9	14.6
1975[c]	142 045 (0.0)	138 333 (0.0)	280 378 (0.0)	129.0	15.8
1980	152 574 (7.4)	218 767 (58.1)	371 341 (32.4)	157.6	15.0
1985	221 279 (55.8)	265 481 (91.9)	486 760 (73.6)	184.0	11.2
1990	271 174 (90.9)	271 178 (96.0)	542 352 (93.4)	188.2	10.0
1995	342 245 (140.9)	299 884 (116.8)	642 129 (129.0)	210.1	8.7

Source: Department of Statistics, various years.
[a]Include private cars and company cars.
[b]Figures in brackets indicate percentage increases over 1975 figures.
[c]From 1974, records on motor vehicles were computerised. Pre-1974 figures such as the 1970 figures were found to be slightly over-estimated, thus accounting for the drop in the number of vehicles in 1975 compared to 1970.

Figure 1 View of an overhead gantry used in the Area Licensing Scheme

restraint on vehicle ownership called the Vehicle Quota System (VQS). The ultimate control of vehicle population by the VQS virtually ensures that increases in the number of vehicles will not exceed a predetermined ceiling on net increase of vehicle population (currently 3% per annum),[2] regardless of the rate of national economic growth. Restraining vehicle quantity by the VQS, although resulting in high, largely unaffordable car prices, has proved an effective complementary measure to road pricing in alleviating traffic congestion. An in-depth analysis of the VQS is undertaken in Foo (1998).

Electronic road pricing in Singapore

Singapore's ERP system is the first of its kind to be used on an extensive scale to manage traffic congestion (The Straits Times, 1998a). Its aim is to selectively impose charges on vehicles using the main criteria of contribution to congestion There have been other electronic payment systems used elsewhere in the world such as in Canada, USA and Norway but they differ from Singapore's ERP system in three ways. Firstly, most are small scale systems, covering one or a few highways; secondly, most use a centralised billing system instead of Singapore's direct debiting system, and, thirdly, most systems elsewhere are used essentially to recover costs of road construction as well as yield returns but not primarily to control congestion.

Development of the ERP system

A decade after the launching of the ALS, government officials visited Hong Kong in 1985 to get first hand knowledge of ongoing ERP trials. In 1989 the government approved in principle the use of ERP for Singapore roads. Transport officials made trips to cities in USA and Europe where state-of-the-art electronic toll systems were in operation. A major decision was made in 1991 to use smart card technology and this was followed by the calling of bids for the ERP con-

[2]This ceiling is flexible and can be changed to suit prevailing traffic conditions in the country.

Table 2 Chronology of major events in the development of the ERP system

1975	Introduction of the Area Licensing Scheme (ALS).
1985	Government officials study the ERP trial in Hong Kong.
1989	Government approves in principle the ERP system.
1991	Government approves a smart card system for ERP. Pre-qualification tenders called.
1992	Five consortiums are shortlisted for ERP contract.
1993	Tenders further narrowed to three consortiums. Road tests conducted.
1995	Final bids made by three consortiums. ERP contract goes to Philips consortium at S$197 million, plus maintenance for five years at another S$39 million.
1997	More road tests undertaken by Philips consortium. Publicity campaign launched. Installation of in-vehicle units in cars starts from September 1997 to July 1998.
1998	ERP starts on the expressways and then extended to all other areas on September 1.

tract. After the shortlisting of bids and road tests,[3] the ERP contract worth S$197 million (US$116 million)[4] was awarded to the Philips consortium[5] in 1995.

Further road tests and tests on in-vehicle units (IUs),[6] which were gadgets for debiting of charges, were undertaken followed by the fitting of the IUs for all motor vehicles in 1997–98 at over 160 IU installation centres (such as at vehicle inspection centres, motor workshops and mobile units). The fitting of IUs was free of charge and voluntary during the period.[7] By July 1998, 96% of 680 000 vehicle owners had fitted their vehicles with IUs. Table 2 summarizes the chronological development of the ERP system.

Operational and technical features

Fig. 2 shows the present boundaries of the ERP's (and earlier, the ALS's) Restricted Zone. It was estimated that in 1990 315 000 people were employed within the zone (Menon and Seddon, 1991). The Restricted Zone is about 725 hectares with 27 ERP entry points around its boundary. There are 6 more ERP gantry locations on expressways outside the Restricted Zone (two on the East Coast Parkway, one on the Pan-Island Expressway and three on the Central Expressway). All entry points are demarcated by prominent signs with LCD displays mounted on overhead gantries (Fig. 3). During the hours of operation, the words "In Operation" are flashed on the LCD panels of the gantries at all 33 entry points.

The ERP system uses a sophisticated combination of radio-frequency, optical-detection, imaging and smart-card technologies. To motorists, the three main visible components are the gantries, the in-vehicle unit and the smart card (called the "CashCard"). The system can handle multiple vehicles traveling at speeds of more than 120 km h^{-1}.

At each ERP entry point, there is a pair of overhead gantries which are 6 m high and 15 m apart (Fig. 4). Each gantry has a set of two antennae, two cameras and two optical detectors per lane. Upon detection of an incoming vehicle and within a fraction of a second, the ERP system communicates with the in-vehicle unit (IU), identifies the type of vehicle, deducts charges, and if a violation is detected, captures the image of the vehicle and its license plate.

Information about errors and violations is sent by a ground-level control box called the "outstation controller" via telephone cables to a central computer system located at the LTA's control centre. The central computer churns out reports of offences and system errors and mails these reports to the vehicle owners. Presently, those caught going past a gantry without an IU have to pay a fine of S$70 while those without a CashCard or insufficient balance in the CashCard will have to pay an administrative surcharge of S$10 plus the undeducted ERP charge involved. Technical details of the detection, debiting and enforcement process are given in Appendix A.

The second ERP component, the pocket-sized IU, uses only a small amount of power tapped from the vehicle battery, and is permanently attached to the car windscreen by a bracket glued on using a special adhesive (Fig. 5) or attached by brackets to the motorcycle's speedometers (Fig. 6). Each IU has a back-lit LCD display to show the cash balance in the smart card used.

The third component, the stored-value smart card or CashCard, is issued by NETS (Network for Electronic Transfer) which is a company owned by a consortium of local banks. The stored value can vary from S$20 to S$500. The card is sold at banks, post offices and petrol stations and can be topped up at

[3]For three shortlisted consortiums, rigorous tests at experimental ERP gantries were conducted in 1994 under all types of traffic conditions such as extreme heat, poor visibility in heavy rain, vehicles reversing and hiding behind or between large trailers, high speed driving and power failures. The winning Philips consortium was second lowest in the bid but first in reliability with an error rate of one in 100 000 transactions.

[4]The present currency exchange rate is S$1 = US$0.59 or US$1 = S$1.70.

[5]The consortium comprises of the following corporations: Philips, Mitsubishi Heavy Industries, Miyoshi Corporation and CSE Engineering. During the testing phase of over two years prior to implementation, the ERP system was put through some 5 million transactions by the consortium.

[6]In the design stage, the IUs were subjected to extreme tests — they were to be water-proof, crash-proof, able to withstand high temperatures and have very low error rates. They had to be durable (a minimum five-year warranty period), easy to install and use, and when in use, able to provide motorists with information on the state of the IU and CashCard. CashCards too needed to be heat resistant.

[7]For subsequent installation of IUs after the designated period, a fee of S$150 is charged.

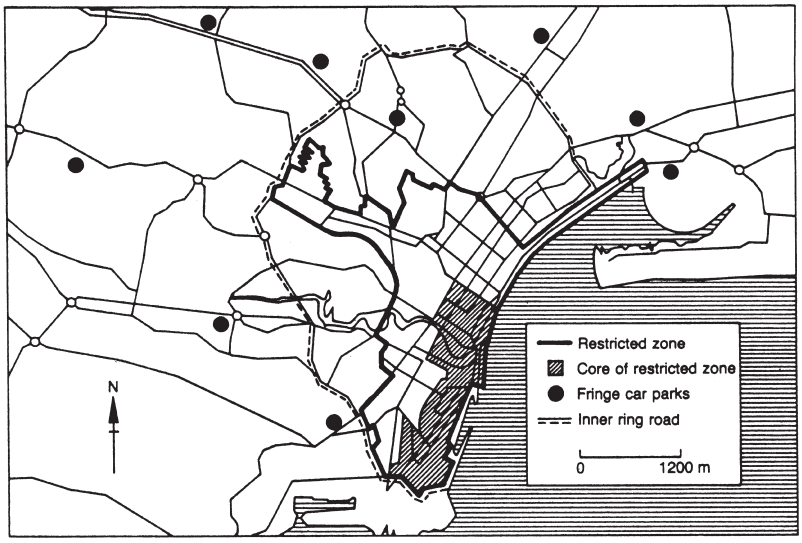

Figure 2 The Restricted Zone covered by the ALS and ERP system. Source: Lewis (1993). Note: The core area is the CBD; fringe car parks offer park-and-ride services, and the inner ring road is a bypass route

Figure 3 An ERP gantry location in a busy part of Singapore's CBD

automatic teller machines. Technical features of IUs and CashCards are described in Appendix B.

Structure of ERP charges

ERP rates are set based on the Passenger Car Unit (PCU) ratings of motor vehicles and includes the phasing in of charges for commercial vehicles and taxis. The PCU ratings (in brackets) for different types of vehicles are 1.0 for cars (private/company), taxis and light goods vehicles, 0.5 for motorcycles, 1.5 for heavy goods vehicles and small buses (30 seats or less), and 2.0 for very heavy goods vehicles and big buses (more than 30 seats).

LTA has planned for ERP charges for taxis (which are borne by passengers) to be phased in over a 3-year period in recognition of the role of taxis as a personalised form of public transport. As for commercial vehicles, ERP charges are to be phased in over a 4-year period to help businesses adjust their business operations to the new road pricing system as well as to lessen their financial burden given the current poor financial and economic conditions in Singapore and the Asian region. Hence, for the first year, the rates for goods vehicles and buses were set at 25% of their full ERP rates, while that for taxis were one-third of their full ERP rates.

Table 3 shows the calculation for the present range of ERP charges for vehicles entering the Restricted Zone in the 7.30 am to 8.00 am period during weekdays. As shown, ALS rates prior to the implemen-

Figure 4 A side view of the pair of overhead gantries

Figure 5 The IU is normally located in the lower right-hand corner of the windscreen

tation of the ERP system were higher than ERP rates. Among the different types of vehicles, cars are presently charged the highest rates at all times of the day. The breakdown of ERP rates for cars entering the Restricted Zone and expressways on weekdays[8] is given in Appendix C.

Early impacts and responses

Errors and violations

Three months after implementation, the ERP system's error rate was found to be an acceptable 0.07% (The Straits Times, 1998h). Errors were traced mainly to faulty IUs and CashCards as well as gantry communication errors.

As for violations by motorists, of the estimated 280 000 motorists who passed through ERP gantries daily, some 800 violations (0.3%) were detected daily. Although there are three categories of violations — "no IU", "no CashCard" and "insufficent balance in CashCard", over 90% of violations occurred because the motorist forgot to put in the CashCard (i.e. "no CashCard").[9]

[8]Prior to the revision of rates in April 1999, ERP rates were also set for Saturday mornings.

[9]The ERP system is capable of distinguishing between a system error and a violation. When a CashCard is inserted correctly but the CashCard or IU is faulty, the ERP system will not detect a violation but register a system error. If system errors are detected, motorists are not fined but sent a notice to check their IUs and CashCards. As for fines due to violations, motorists can appeal and

Figure 6 The motorcycle IU has a protective covering to prevent rainwater seepage

Table 3 Structure of ERP charges for entering the Restricted Zone from 7.30 to 8.00 am on weekdays (as of July 1, 1999)

Type of vehicle	PCU rating	Phasing-in period (yr)	Rate payable now (%)	ERP charge (S$)	ALS charge (S$)
Car (private/company)	1.0	–	100	1.00	3.00/6.00[a]
Taxi	1.0	3	33	0.30	3.00
Light goods vehicle	1.0	4	25	0.25	3.00
Motorcycle	0.5	–	100	0.50	1.00
Heavy goods vehicle/small bus	1.5	4	25	0.40	3.00
Very heavy goods vehicle/big bus	2.0	4	25	0.50	3.00

[a] The ALS rates for private cars and company cars were S$3.00 and S$6.00, respectively. ALS charges were valid for multiple trips within a day.

Revenue collection

It was found that the ERP system, in its first month of operation, collected S$6.6 million, this being 23% less than the monthly S$8.6 million average revenue collected under the previous ALS (The Straits Times, 1998d). However, the ERP system is estimated to cost S$9 million a year to operate compared to the S$17 million annual operating cost experienced under the ALS in 1997. Nevertheless, controlling traffic congestion, and not revenue collection, is the primary objective of the ERP system.

Traffic conditions (CBD)

In the month of September 1998, it was found that average daily traffic flow during weekdays in the Restricted Zone fell in volume by 20 to 24% from over 271 000 under the ALS to between 206 000 and 216 000 (Table 4). Traffic speed rose from 30 to 35 km h^{-1} under the ALS to 40 to 45 km h^{-1} under the ERP system. On Saturdays, traffic volumes fell by 19%. It was also found that higher ERP charges from 3.00 to 5.30 pm on weekdays for the Orchard Corridor, which is a part of the Restricted Zone, led to 44% fewer motorists (The Straits Times, 1998f).

The implication of the fall in traffic volume is that some motorists have reduced their number of trips on ERP roads, some have switched routes to non-ERP roads or changed commuting time to non-ERP hours while others have switched to public transport (buses and mass transit) for some or all of their trips. The short and long term impacts of the ERP on public transport usage is in particular an important area of further research.

In general, road users and businesses in the Restricted Zone benefited from less congestion on the roads. However, the large fall in traffic volume showed some degree of under-utilisation of road capacity.

if the appeal is based on possible system error, a check on the IU and CashCard can be conducted.

Table 4 Impact of ERP on daily traffic volumes and speeds in September 1998

	Traffic volume (no. of vehicles)			Traffic speed (km/h^{-1})	
	Pre-ERP	**Post-ERP**	**Change**	**Pre-ERP**	**Post-ERP**
Areas covered under ERP					
Restricted Zone	271 051	206 000 to 216 000	−20% to −24%	30–35	40–45
East Coast Parkway	16 203	14 400 to 14 900	−8% to −11%	36–67	55–65
Central Expressway	12 398	15 200 to 15 800	23% to 27%	45–63	35–50
Pan-Island Expressway	8020	9400 to 9900	17% to 23%	55–59	55–60

Source: The Straits Times (1998e).

Traffic conditions (expressways)

Traffic flow on the expressways, except for the East Coast Parkway, swelled by some 23 to 27% for the Central Expressway and 17 to 23% on the Pan-Island Expressway (see Table 4). In the case of the Central Expressway, traffic speeds fell from 45 to 63 km h^{-1} previously to 35 to 50 km h^{-1}. Traffic studies revealed that the lower ERP rates for taxis and goods vehicles for expressways compared to roads in the Restricted Zone had attracted more taxis and goods vehicles to these expressways (The Straits Times, 1998e). For instance, it was found that for the Central Expressway, the number of taxis and goods vehicles increased by 90% and 64%, respectively.

Taxis (CBD)

There was a fall in the number of taxis entering the city without passengers as drivers of such taxis have to bear the ERP charges themselves each time they enter the CBD (unlike the previous flat fee system under the ALS). As a result, taxi commuters originating from the CBD had to wait in long queues since the only taxis available were mainly those which were driven into the CBD with passengers.[10] A study undertaken by a taxi company found that the average waiting time for taxi commuters at three popular taxi stands in the CBD in the afternoon between 4.00 pm to 6.00 pm rose from between 4 to 5 minutes to 6 to 9 minutes since many taxi drivers refrained from entering the CBD without passengers (The Straits Times, 1998c).

Responses by LTA

As a result of the above impacts, instead of waiting for its planned quarterly review in December 1998, the LTA made a quick revision to ERP rates on Nov 2, 1998 (The Straits Times, 1998g). To alleviate congestion on the Central Expressway, the LTA brought forward the second stage of the phasing in of ERP rates for taxis and goods vehicles using the Central Expressway. From November 2, 1998, taxis using the Central Expressway were charged two-thirds of their full rates while goods vehicles were charged half of their full rates. For taxis, rates thus increased from a range of S$0.35 to S$0.70 to a range of S$0.70 to S$1.40 while for goods vehicles, rates increased from a range of S$0.25 to S$1.00 to a range of S$0.50 to S$2.00.

For roads in the Restricted Zone, which were generally under-utilised, weekday rates were reduced by S$0.50 per PCU (amounting to between S$0.10 to S$1.50 less) for all vehicles entering the Restricted Zone so as to put more traffic on underused roads. A lower and flat ERP rate on Saturdays was also put into effect. It was hoped that lower rates would encourage more taxis to drive into the city without passengers.

As the rate of under-usage of roads in the Orchard Corridor (which is part of the Restricted Zone) was relatively greater than other parts of the Restricted Zone, higher charges for the Orchard Corridor between 3.00 to 5.30 pm were removed so as to ensure a uniform rate at all entry points into the Restricted Zone. With the across-the-board reduction in rates, more traffic was expected to come into the Restricted Zone but the projected increase was estimated to reach a level that would not lead to any significant congestion within the zone.

A later study on traffic volumes and speeds during the months of November 1998 to March 1999 revealed that only minor changes to ERP rates were needed (The Straits Times, 1999c). The LTA announced its selected criteria of optimum travel speed range of 45–65 km/h^{-1} for expressways and 20–30 km/h^{-1} for arterial roads in the Restricted Zone and adjusted ERP rates where necessary (The Straits Times, 1999b). For time periods and routes where travel speeds exceeded the prescribed optimum range, ERP rates were lowered. Examples include the waiver of charges on Saturday mornings and lowering of rates for the 7.30–8.00 a.m. period for gantries in the Restricted Zone. For time periods and routes where travel speeds fell below the prescribed optimum range, ERP rates were raised. There was thus higher charges for the Central Expressway gantries from 8.00–9.00 a.m. Fig. 7 illustrates the general downward adjustment in weekday rates for cars using roads in the Restricted Zone in the ALS and ERP periods.

[10]Passengers have to pay the ERP charge in addition to the normal taxi meter charge.

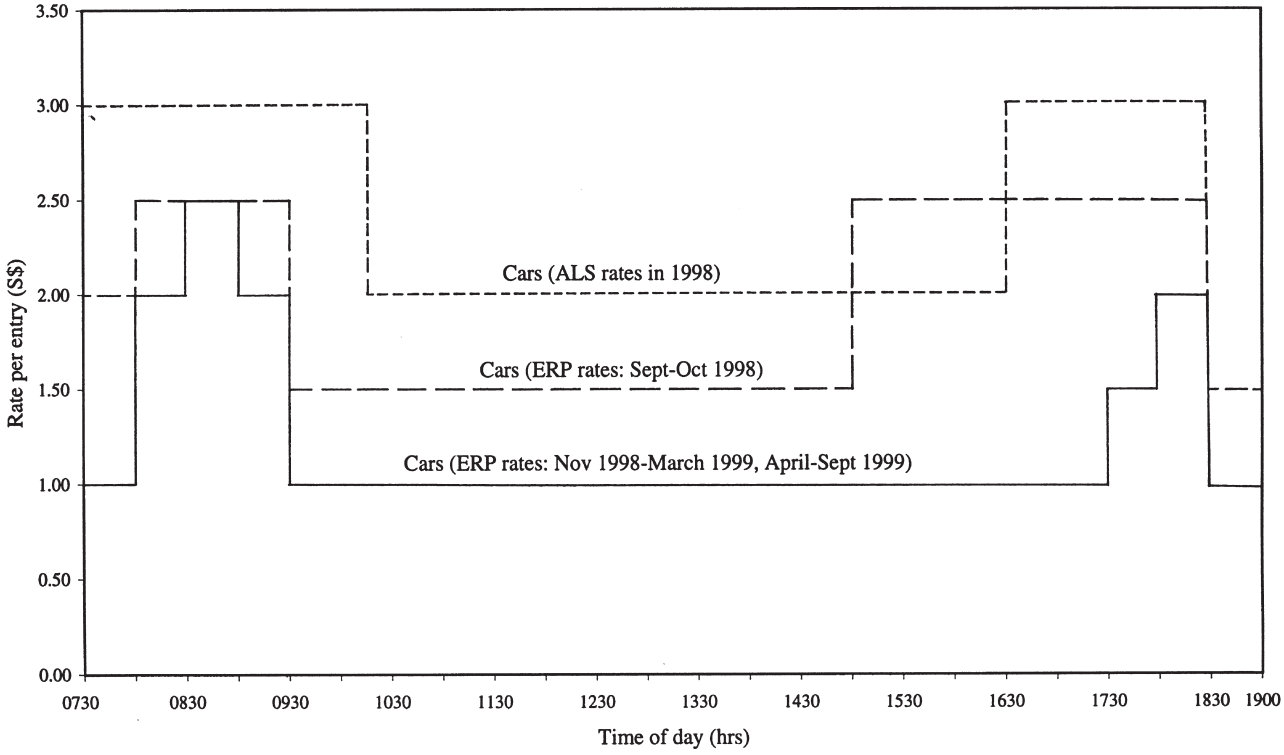

Figure 7 ALS and ERP rates for cars entering the Restricted Zone on weekdays. Note: For ERP rates from April–Sept 1999 see Appendix C. Rates for Nov 1998–March 1999 differ only for 0730–0800 hrs (S$1.50) and 1730–1800 hrs (S$2.00)

Advantages of the ERP system

The ALS, although simple and cheap to operate, was a cumbersome, labour intensive and inflexible form of manual road pricing. Table 5 compares the main characteristics of the ALS and ERP systems.

The ERP system has many advantages over manual road pricing schemes although initial investment costs are considerably higher. It is more efficient and flexible, more equitable and convenient, and has a higher degree of reliability and trustworthiness.

Efficiency and flexibility

In manual road pricing schemes such as the ALS, charges need to be fixed at certain levels for a few years before they can be changed to suit traffic conditions. As such schemes rely heavily on manual labour and paper licenses, it would be technically and administratively difficult for manual road pricing schemes to provide a very flexible system of varying charges in accordance with traffic volume by time and place.

Table 5 Comparison of salient features of the ALS and the ERP system

Features	Area Licensing Scheme (ALS)	Electronic Road Pricing (ERP)
Efficiency of system	Rely largely on labour and paper licences. Not very flexible. Only two types of charges (whole-day and part-day). Charges reviewed after a few years.	Automated electronic system. Very flexible. A range of charges which vary by time and place depending on level of congestion. Charges reviewed quarterly.
Equitability of charges	Licence valid for multiple trips.	Pay-per-entry principle.
Convenience of payment	Purchase of monthly or daily paper licences.	Easy use of smart cards with top-ups at automated teller machines, etc.
Reliability of system	Susceptible to human error and corruption.	Extremely low error rate and technically reliable if well-maintained.
Cost of system	Very low investment cost (S$0.5 million at 1992 rates)[a] but high annual operating cost (S$17 million at 1997 rates).	Very high investment cost (S$197 million at 1995 rates) but low estimated annual operating cost (S$9 million at 1998 rates).

[a] See Foo (1997, p 162).

With ERP technology, charges can be levied on the pay-per-use principle and can vary according to time and area of use. A motorist will be encouraged to choose whether to drive, when to drive and where to drive on the basis of cost, the importance of the trip, and the alternative routes or transport modes available.

The ERP system's flexibility extends to its flexible rate of expansion of ERP boundaries to accommodate the growth of the CBD and increased traffic flow on fringe roads. ERP rates are adjusted quarterly (in January, April, July and October each year) based primarily on the criteria of a pre-determined optimum travel speed range with the overall goal of system-wide optimum traffic conditions. ERP rates are lowered when travel speeds are above the optimum range since this indicates under-utilisation. Conversely, they are increased if speeds fall below the optimum range as this indicates congestion.

In summary, the ERP system brings about a more even flow of traffic by varying road charges according to time and place, depending on the level of congestion With more effective control on congestion and thus releasing spare capacity on the roads, higher car quota allocations can be set (under the Vehicle Quota System) to fulfill the aspirations of more people to own cars in Singapore.

Equity

It is equitable to charge on a pay-per-use or pay-per-entry basis as those who use restricted roads more often should pay a higher charge as they contribute more to congestion. It is thus more equitable than the previous ALS where one area license can be used for multiple trips in and out of the CBD.

Research indicates that in any one day, over 75% of motorists do not use priced roads at all and for those who do, about 80% pass a gantry only once a day (The Straits Times, 1998b). The latter finding means that most motorists driving into ERP zones will be paying less compared to the ALS years since most ERP rates, although on a per-entry basis, are lower than ALS charges (see Table 3). Exceptions include businesses which require frequent trips on ERP-controlled roads such as for deliveries of goods.

Convenience

The ERP system is convenient for motorists as it does away with the hassles of purchasing daily or monthly paper licences under the ALS. CashCards used for the IUs can be easily bought and topped up at any branch of the major local banks, post office outlets and CashCard machines.

Reliability

Unlike the ALS, the ERP system does not need human enforcement personnel at the gantries, thereby removing the potential for human error and saving on labour cost. Each ERP gantry is linked to a central computer at LTA but if there are communication problems, the gantry's "outstation controller" can operate independently for up to 24 hours. The central computer and power supply are duplicated, providing a back-up. A 24-hour command centre and emergency teams on standby have been set up by LTA to safeguard the functioning of the ERP system.

Trustworthiness

An early ERP system (passive type), which was used in the Hong Kong 1983–1985 trial, tagged each car electronically, allowing the central computers to trace the car's movements and bill the owner monthly. Technically it worked but was politically unfeasible as there were fears that the authorities could trace the movements of individuals. The ERP system in Singapore is an active one, based on smart-card technology, where the IUs will be activated only when the vehicle passes through detection points. Transaction records using the ERP direct debiting system are erased as soon as the payment is settled (via NETS), typically within one working day. At ERP gantries, photographs are taken only of violating vehicles. There are stringent internal security and control measures at the LTA's central computer room to ensure that there is no abuse of the system by the staff.

Prerequisites for a successful ERP system

The early experiences from the ERP system in Singapore indicate that there are various operating and technical prerequisites needed for successful implementation of an electronic road pricing system. Firstly, there must be high technical reliability and ability to meet many critical operating requirements and exacting engineering standards. The system must be able to withstand very high usage rates and various environmental conditions. It has to be safe to use as well. For example, motorists must be able to drive through gantries at normal speeds without stopping or slowing down. The IU too must not to be dislodged in a collision.

General technical prerequisites, which apply to all road pricing schemes in general (Foo, 1997, p 162) include:

- erecting road signs to guide motorists who wish to stay outside or inside the CBD;
- demarcating a restricted zone with relatively few entry points for easier enforcement;
- making available attractive alternative transport in the form of public transport systems such as buses, mass rapid transit and taxis, together with special supporting schemes such as shuttle bus routes and park-and-ride facilities;
- accurate setting of peak hours of operations.

Public acceptability is another vital prerequisite to success. Publicity campaigns should stress that the ERP system is simple, easy to understand, user-fri-

endly and hassle-free for motorists. In such campaigns, road authorities should explain that profits made, if any, would be used to improve the overall transport system. The public too needs to be convinced of the effectiveness of road pricing in reducing congestion and in benefiting both users and businesses, perhaps through an initial pilot project or test run.

For cities interested in implementing an ERP system, there are other broader considerations involved. The city must be able to afford or find financing for the huge capital outlay required or could choose to privatise the scheme. The chances of success are better if ERP is marketed as part of an overall transportation package comprising, among other things, complementary demand management instruments as well as investments in public transport and road infrastructure. For example, in the case of Singapore, the ALS and, later, the ERP system are part of a comprehensive transport policy which includes other demand management instruments such as high vehicle ownership taxes and high parking charges within the restricted zone.

Another consideration is the need for an efficient overall system of city traffic management and law enforcement. In Singapore's case, an efficient transport authority together with the help of strict laws and law-abiding citizens contributed to an efficient system of traffic management and enforcement. As noted in Foo (1997, p 163), problems of enforcement and corruption in the ALS were found to be very minimal.

Limitations

A major limitation is the ERP system's very high initial capital investment cost although operating costs may be low. Third World cities may find cost to be a major deterrent unless funding is available or some form of privatization is involved. Once installed, rapid changes in technology may also mean there will be high costs of replacement or upgrading of ERP equipment in a relatively short period of time.

The ERP system is an expensive, major mechanical system which is not completely foolproof. Vehicles can be erroneously charged due to problems such as mechanical errors.[11] For major breakdowns, emergency teams must be on standby for swift recovery. There must also be avenues for appeal by motorists who feel that they may have been wrongly charged. Another potential problem is that of confidentiality. The LTA's central computer is able to store data on the identity of each IU (and thus the owner) for up to 24 hours for the purpose of recording transactions and direct debiting of charges. There could thus be confidentiality problems should abuse of the system occur.

For electronic road pricing to be even more efficient, a real-time ERP system is needed which would charge according to traffic conditions at that moment or point in time. However, this would require a very effective information system which can inform people exactly where the congestion is and how they will be charged before they leave home or when they are driving on the roads. The long term scenario in Singapore is for motorists to view traffic updates on screens in devices fitted inside their cars.[12]

Lastly, for all road pricing schemes in general, there are various inherent limitations. They include:

- businesses locating or relocating outside cordon boundaries, leading to the creation of distortions in travel and land usage at the edges of the zoned area. This may not occur if the degree of benefit enjoyed by businesses and road users through the combined effects of reduced traffic congestion, a better environment and better accessibility by public transport is found to outweigh the burden of paying road pricing charges.
- charges are regressive in nature and works against vehicle owners in the lower income group. To overcome this, revenue collected should be used to compensate the lower income group directly, preferably via channelling of funds into public transport systems
- waiting and queuing on expressway shoulders to enter a gantry just after operating hours. Regular and strict enforcement by traffic police is required.
- congestion on peripheral by-pass roads such as expressways. The most viable solution is for the road pricing system to comprehensively cover all heavily used roads in the city.

Conclusions

While many cities seem to be talking about electronic road pricing or are experimenting with it, Singapore was actually able to launch and implement it successfully. Despite the huge investment cost of the ERP system, its implementation appears justifiable in Singapore as it is a vital component to the achieving of the key objective of the country's land transport policy viz the alleviation of traffic congestion.

[11]For instance, more than 1500 motorists had their ERP charges deducted from their CashCards by mistake (due to a programming error) during a test run on a gantry conducted in August 1998. The charges collected were later fully refunded.

[12]A traffic information system (TrafficScan) which provides real-time data on travelling speeds and congestion through the radio and Internet was launched in early 1999. It uses data tapped from over 7500 taxis via a satellite tracking system (The Straits Times, 1999a). The longer term system, which includes TrafficScan and other intelligent transport schemes, is called the Integrated Transport Management System (ITMS). The ITMS is envisaged to be fully developed by 2002. It will facilitate the collection, processing, sharing and dissemination of transport information. It will not only be able to give online traffic information but also give advice on the best and fastest travel modes and routes, taking into account congestion and ERP charges.

The ALS, a manual road pricing scheme started in 1975, laid the foundations for the more technologically advanced ERP system. The early experiences so far with the ERP system have shown it to be efficient and effective in curbing traffic congestion. As a system which selectively imposes charges on vehicles by type of vehicle, place and time using the main criteria of contribution to congestion, it has led to a more allocatively efficient level of traffic volume and better utilisation of road capacity. The system was also found to be equitable, flexible and reliable. Various prerequisites and limitations of the system need to be considered for the ERP system to be successfully implemented in other cities.

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Appendix A

Vehicle detection and charging process at the gantries

The communication process starts some 10 m (or a second away for a moving vehicle) before the first gantry. As a vehicle approaches the first gantry, it is detected by the first antenna. A ground-level control box called the "outstation controller" is located nearby and coordinates the whole process. It communicates with the IU of the vehicle by radio frequency via the first antenna to, firstly, check for the presence of a CashCard; secondly, to check for the balance in CashCard value; and, thirdly, to execute debiting instructions to the IU if everything is in order.

A "vehicle presence detector" (using an optical line sensor) mounted on the second gantry visually identifies the type of vehicle and pinpoints its location. The black and white stripes on the road ("marker lines") act as a ruler from which the detector is able to determine the type of vehicle passing through by calculating the number of stripes covered and the duration of the pass. At the same time, the second antenna, which is also mounted on the second gantry, communicates with the IU and acts as a confirmation device.

With information from the two devices on the second gantry, the "outstation controller" confirms or verifies, firstly, the presence of a valid CashCard and IU; secondly, the availability of sufficient balance in CashCard value; and, thirdly, the correct deduction for the type of vehicle going through the gantry. If the transaction is valid and accepted, the "outstation controller" will instruct the IU to display its new CashCard balance. If a CashCard has been inserted but there is no transaction or the transaction is invalid, an error message will be seen on the IU display. Additionally, there will be a continuous beeping sound. Only when the IU is in working order and the transaction is valid will there be a small beep and a display of the balance of the CashCard value. If any system error or violation is detected, the charge-coupled device (CCD) camera mounted on the first gantry is instructed to photograph the back of the vehicle.

Appendix B

Technical features of in-vehicle units (IUs) and CashCards

For security purposes, unique security codes are assigned to each IU. The IUs are also colour coded for different types of vehicle classes as ERP charges vary among different vehicle classes. The vehicle classes are cars, taxis, motorcycles, light goods vehicles, small buses, heavy goods vehicles, large buses and emergency vehicles. The installation process takes about 30 minutes per vehicle. For safety and other technical reasons, the best position to fit the IU is the lower right-hand corner of the windscreen (except for taxis where it is located in the middle lower edge of the windscreen for visual display to passengers). In the case of foreign vehicles, owners can pay for the installation of the normal permanent IU or rent a temporary, detachable IU.

To ensure that motorists are not caught unwittingly with insufficient cash balance in the CashCard, there is a long beeping sound whenever the cash balance in the CashCard falls below S$5 (which is usually enough for at least two more passings under the ERP gantry). A cash balance of less than S$5 remains on the IU display (the cash balance display goes off after 10 seconds if the value exceeds S$5) to remind motorists to top up the cash value of the CashCard The CashCard is designed to be able to withstand long periods of high temperatures as typically experienced inside a vehicle when it is parked under the hot sun for long periods of time. The CashCard should also be usable for other cash transactions in supermarkets, petrol stations, etc.

Appendix C. Rates for cars passing through ERP gantries in the Restricted Zone and on expressways (as of July 1, 1999)

Rates (in S$) for entry per vehicle	**7.30 am–8.00 am**	**8.00 am–8.30 am**	**8.30 am–9.00 am**	**9.00 am–9.30 am**	**9.30 am–5.30 pm**	**5.30 pm–6.00 pm**	**6.00 pm–6.30 pm**	**6.30 pm–7.00 pm**
Mondays to Fridays								
A. Restricted Zone	1.00	2.00/2.50[a]	2.50	2.00	1.00	1.50	2.00	1.00
B. Expressways								
East Coast Parkway	1.00	1.50	2.00	0.50	–	–	–	–
– Central Expressway	1.00	2.50	2.50	1.00	–	–	–	–
– Pan-Island Expressway	1.50	1.50	1.00	0.50	–	–	–	–
Saturdays								
A. Restricted Zone[b]	–	–	–	–	–	–	–	–

[a]Rates for Nicoll Highway only.
[b]Free for the quarters under review (April–September 1999) but prior to April 1999, charges were levied on Saturdays for entry from 8.30 am to 1.00 pm.