International Transport Forum

Congestion Control in Singapore

Discussion Paper

183 Roundtable

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Singapore University of Social Sciences

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The International Transport Forum

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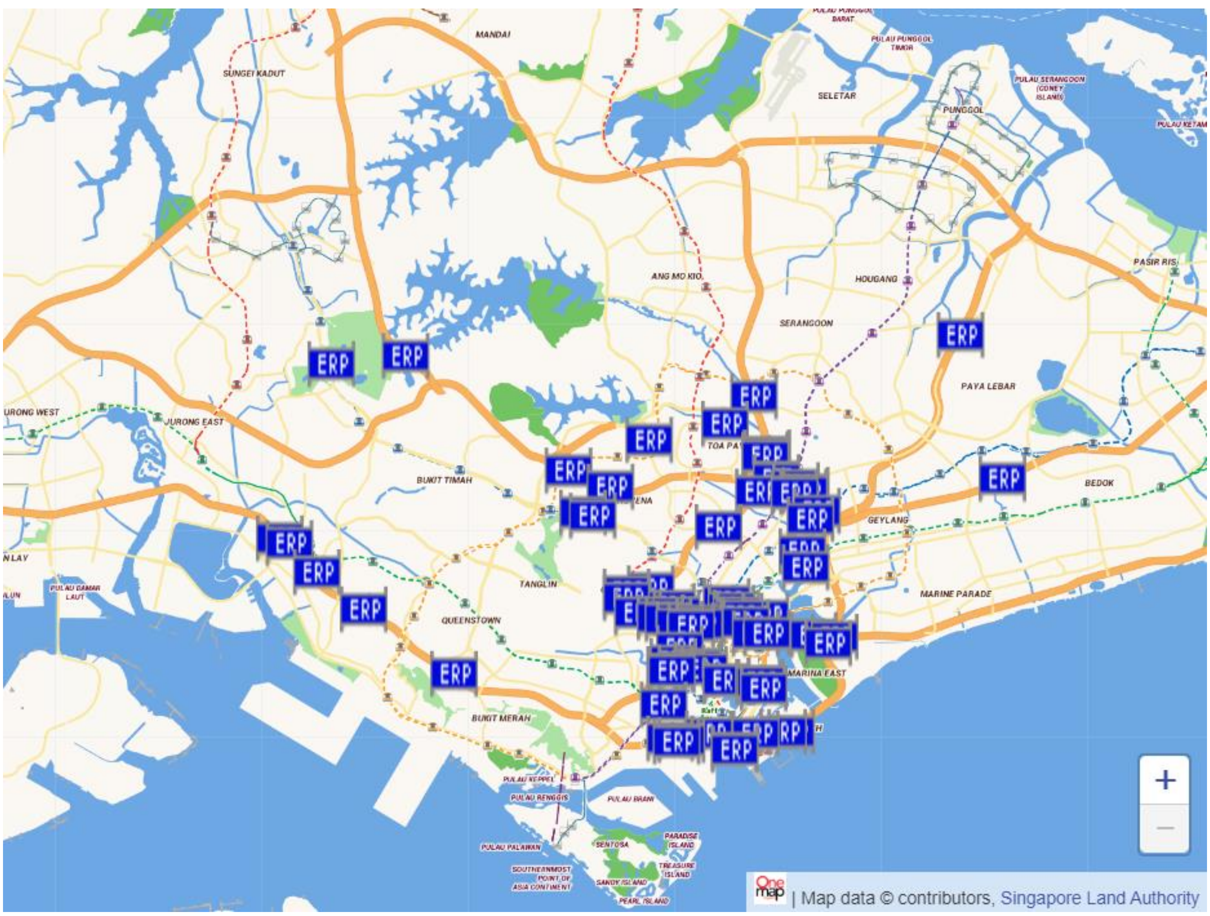
Introduction

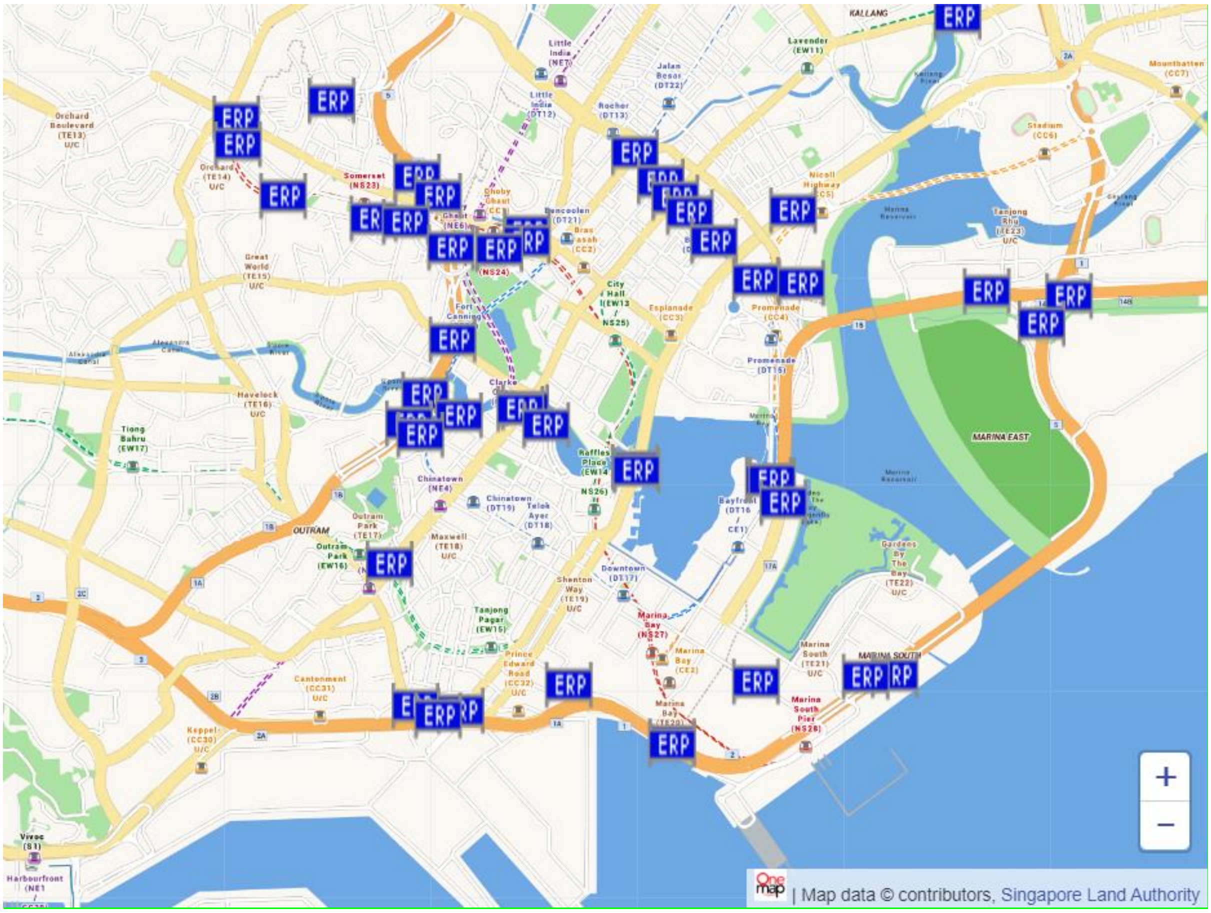
As of 2020, Singapore has perhaps the most complex, comprehensive, and technologically sophisticated urban Electronic Road Pricing system in the world. A network of 93 overhead gantries (Figure 1) situated at key arterial routes, expressways, and circling the central business district (Figure 2), automatically levy road charges on passing passenger vehicles, which are mandatorily equipped with in-vehicle transponder units. Road charges vary from SGD 0.50 to over SDG 5.00 and are adjusted in as little as five-minute increments, to maintain road speeds of 20 km/h to 30 km/h in the central business district and 45 km/h to 65 km/h along expressways. The present Electronic Road Pricing system has been in operation since 1998 but was preceded by manually operated road pricing in the central business district from as early as 1975 (For a comprehensive review, see Phang and Toh, 2004).

Figure 1. Singapore Electronic Road Pricing Gantries as of September 2020



Source: Land Transport Authority Singapore (2020), https://www.onemotoring.com.sg/content/onemotoring/home/driving/ERP.html (accessed 1 September 2020)

Figure 2. Central Business District Electronic Road Pricing Cordon as of September 2020



Source: Land Transport Authority Singapore (2020), https://www.onemotoring.com.sg/content/onemotoring/home/driving/ERP.html (accessed 1 September 2020).

While congestion pricing is in principle an efficient solution to road congestion, implementation in many cities has been stalled by political resistance. One common view is that Singapore's successful implementation of road pricing is explained by strong government control and the general compliance of the Singaporean public with government directives (Phang and Toh, 2004; Gu et al., 2018). As a result, the political challenges and policy compromises inherent to Singapore's road pricing strategies have been somewhat neglected.

In reality, the development of Singapore's road pricing system has depended on overcoming the same sources of political resistance that contest vehicle and congestion policy reforms elsewhere. Singapore policy makers have had to carefully negotiate underlying aspirations for private car ownership and usage in a rapidly growing and increasingly affluent population. The implementation and expansion of road pricing on Singapore roads has been justified to the public as a means of permitting expanded private car ownership, effectively combining the carrot of expanded car ownership with the stick of congestion pricing policy. Unlike many cities, Singapore has long imposed price-based restraints on both vehicle ownership and use. Managing congestion policy has therefore required Singapore policy makers to make fine political judgments on which policy lever – ownership or usage – is likely to generate the most effect on congestion with the least political cost.

The technological sophistication of Singapore's Electronic Road Pricing system – soon to be replaced with an even more advanced satellite-based system – is belied by reliance on a straightforward road pricing model. Prices are adjusted quarterly to maintain traffic speeds within target road speed bands, as determined by speed-flow traffic studies. The aim is to maximise vehicle flow in congested routes, on the assumption that this also approximates the efficient outcome where the social marginal cost of driving is aligned with the private marginal cost. There has been no published official attempt to estimate the welfare effects of the congestion pricing system, nor to estimate the demand system for use of congested roads. The question has also attracted relatively little attention from academic researchers, in part because detailed official data on traffic counts or on motorist usage of the ERP system has rarely been made publicly available; exceptions are Olszewski and Xie (2005) and Xie and Olszewski (2011).

Thus, while Singapore's road pricing system is technologically capable of implementing more complex electronic road pricing methods, such as the real-time dynamic prices used in High Occupancy Toll systems, such methods have not yet been explored in depth for application in Singapore, either in theory or in practice. The next-generation Global Navigation Satellite System (GNSS) -based road pricing system, scheduled for vehicle installation in 2021 (the road infrastructure has already been installed), will be a direct replacement for the existing gantry-based system, with no immediate plans to employ more complex charging mechanisms such as distance-based pricing.

Singapore's road pricing system is now at a turning point, not just because of the scheduled technological change to GNSS-based charging, but also because policy makers have run out of headroom to balance the benefits of expanded vehicle ownership with politically costly vehicle usage restraints. Since 2016, policy makers have replaced the previous strategy of catering to aspirations for expanded vehicle ownership with an emphasis on urban mobility facilitated through public transport, shared transport, and active mobility. The car growth rate in Singapore has been set to 0% since early 2018, and as a result, road pricing can no longer be promoted as a policy that facilitates enhanced car ownership and use.

This paper will discuss the political and economic context for the development of road pricing policy in Singapore and the legislative basis for road pricing, followed by the technical development and characteristics of the next-generation GNSS-based system. The paper will then discuss the economic basis for and effects of road pricing in Singapore, and conclude with some research questions that will have to be addressed to unlock more potential from the next-generation GNSS-based system.

Political and economic context of road pricing policy in Singapore

Unlike many developed cities where road pricing plans have been formulated in the context of a population where car ownership is mature, road pricing policies in Singapore were initiated during a period of rapid economic development which saw the country transition from low income to high income within the space of a generation. GDP per capita in USD stood at about USD 500 at independence in 1965, was USD 2 500 in 1975 when the Area Licensing Scheme (precursor to the present Electronic Road Pricing system) was implemented, and was about USD 22 000 in 1998 when Electronic Road Pricing was implemented.[1]

This dramatic increase in population income was accompanied by burgeoning demand for private car ownership. From 1965 through 1990, when the vehicle quota system (VQS) was imposed to strictly limit vehicle growth, the number of privately owned passenger cars more than doubled from 104 729 to 247 808 – an increase from about 55 cars to 81 cars per thousand population.[2] Private passenger car ownership as of 2019 stood at 515 036 vehicles, a ratio of about 90 cars per thousand population. While car ownership rates remain low compared to most developed countries, Singapore's rapid vehicle growth rate has taken place in a land-constrained island which, land reclamation, rural development, and road building notwithstanding, has limited ability to accommodate vehicle use without excessive congestion.

Policy makers in Singapore faced a dilemma: how to enable the population, particularly the growing middle class, fulfil their aspirations for car ownership, while maintaining efficiently low levels of congestion in the road network for commercial purposes and to facilitate public transport. To address this dilemma, policy makers have, first, drawn the attention of the public to the limited road capacity and land constraints of the island, highlighting the risk of unconstrained vehicle growth with reference to both domestic traffic congestion and the heavy congestion experienced in comparable cities worldwide; second, having convinced the public that some restraints on vehicle ownership and use are necessary, sought to define the policy debate as one between choosing the right balance between ownership-based and usage-based restraints, while accommodating household aspirations and transport needs. Through this, policy makers have largely been able to marginalise arguments to abolish vehicle restraints completely, and have focused public attention instead on variants and refinements to the existing restraint policies.

The Road Transport Action Committee and the Area Licensing Scheme in 1975

Singapore's rapid economic growth following independence in 1965 generated a significant expansion of demand for transport services. Following the redevelopment of the central business district, employment in the central area grew nearly fivefold. Yet road space only doubled, leading to severe congestion. Privately operated public transport services were disorganised and unsatisfactory, leading to a government-led restructuring of the public bus system in 1971 and a crackdown on unregulated "pirate taxis". In 1973, a high-level Road Transport Action Committee (RTAC) was formed to:

> (a) [accord] high priority to the public bus service; and (b) [adopt] various traffic management measures to reduce the present congestion on [the] streets. (Singapore Parliamentary Debates, 1974)

The Road Transport Action Committee identified the heavy congestion generated by privately owned cars as a major factor behind the poor performance of public transport services. Besides introducing priority bus lanes, staggered working hours, and other traffic demand management measures, the RTAC also proposed introducing a license charge for entry into the Central Business District during peak hours in the morning.

The Area Licensing Scheme (ALS), implemented in 1975, defined a "Restricted Zone" around the Central Business District. Entry to the Restricted Zone from 7.30 am to 9.30 am on workdays required motorists to purchase and display a Day License, at an initial cost of SGD 3.00 per day. In convincing the then-small motoring public to accept the ALS, policy makers followed the practice elsewhere of sweetening alternatives to private motor transport. A comprehensive system of shuttle-serviced park and ride facilities was set up around the periphery of the Restricted Zone, to offer motorists the option to continue using vehicles freely except in the most congested parts of the city. The focus was on shifting motorists in low occupancy private passenger cars entering the central business district to consider carpooling or park and ride facilities situated at the periphery of downtown (Road Transport Action Committee, 1974). Consistent with the focus on low-occupancy private cars, the initial licensing scheme exempted most other types of vehicles from pricing, as well as high occupancy vehicles, and charged only for entry during the morning peak. However, over time exemptions were reduced, and the charging window expanded (Chin, 2002; Phang and Toh, 2004).

By the 1980s it was increasingly clear that notwithstanding the effect of ALS on managing peak-hour traffic in the city centre, congestion problems were building up rapidly elsewhere on key arterial routes and expressways. Passenger car ownership, which in the 1960s and early 1970s had been confined to the then-small upper middle class, was rapidly expanding in tandem with a growing middle class. From 1980 to 1990, the private passenger car population increased from 134 897 to 247 808 – a compound annual growth rate of 6.2% – despite increasingly heavy import taxes and registration fees imposed by the Government as part of the vehicle ownership restraint policy. In 1985, the Government began studying the feasibility of implementing a computerised replacement for the ALS, eventually to be termed Electronic Road Pricing, as a means of progressively expanding road pricing outside the central business district.

The Select Committee on Land Transport Policy and the vehicle quota system in 1990

As a corollary measure, the Government also floated the idea of introducing a firm control on vehicle growth, through the creation of a quota system for vehicle ownership. These proposals attracted significant public attention. In August 1989, Parliament convened a Select Committee on Land Transport Policy, to examine, among other questions, "[i] … the need for measures to curb road usage and the effectiveness and appropriateness of measures currently in force; [ii] … current policies for controlling the population of motor vehicles…" The Committee convened meetings over five months, receiving 71 written representations and hearing evidence from 28 groups.

Section 15.1 of the Committee's Report summarises the Committee's view on the question of ownership versus usage restraints, and are reproduced below (Parl. 1 of 1990):

> The Committee observes that there is a tendency for members of the public to regard usage restriction measures like Electronic Road Pricing (ERP) as the panacea for the road congestion problem. This misconception should be dispelled. Usage measures, when extensively applied, are likely to be just as painful if not more painful than ownership measures. They also carry the odium of being recurrent, on a daily basis, as compared to ownership restraints which are largely of a one-time nature.
>
> The correct way to view usage restraint is that it is a supplementary instrument to sharpen the efficacy of ownership restraint measures. Effective usage measures such as the ALS make it more costly to operate a vehicle during heavy traffic periods in congestion prone areas such as the Central Business District (CBD). They, therefore, restrain the use of vehicles during these hours and enable the road system to sustain a higher rate of car ownership by the population…
>
> The judicious application of usage measures can therefore raise the level of car ownership in Singapore and help satisfy the aspirations of a proportion of the population who wish to own cars for reasons of prestige or convenience for social activities and are willing to leave them at home and use the public transportation system for commuting to work.

Two important political points emerge from the Committee's work. The first is that politicians perceive the psychological impact, and hence political cost, of usage restraint measures to be relatively high compared to that of ownership restraints. The second is that politicians recognise that the aspirations of the population to own cars, including (or perhaps especially) for “prestige” or “social activities” must be satisfied, particularly if that can be achieved without imposing congestion on the road network. The Committee’s report represents one of the clearest expressions of the Government’s political strategy with road pricing.

The Committee’s Report was accepted by the Government and used as the basis for the introduction of the Vehicle Quota System in 1990. Under the Vehicle Quota System, a motor vehicle can only be registered for use in Singapore if the owner possesses a valid Certificate of Entitlement (COE), which is permanently linked to the vehicle on registration. COEs are released periodically and the price, or “Quota Premium”, is set by auction. Vehicles may maintain their registration for ten years, at which point the COE expires and a new Certificate must be obtained (from the prevailing Quota allotment then) to continue registering the car for road use. While the VQS successfully controlled vehicle growth and has become a major contributor to Government finances, it also placed a high price tag on vehicle ownership that became a political concern. Quota premiums in some years rose to multiples of the average annual income, and vehicle registrations were often dominated by luxury brands, despite attempts to carve out sub-quotas for mass-market vehicles. Perceptions that car ownership was being priced out of reach for the middle class were addressed by a succession of schemes that, in addition to sub-quotas by vehicle type, also attempted to carve out vehicle ownership entitlements for social purposes, by granting discounts to vehicle taxes for vehicles restricted from any road use during peak hours.

Introduction of the Electronic Road Pricing system in 1998

In the context of a maturing Vehicle Quota System and Area Licensing Scheme, the technical trials of the Electronic Road Pricing system were finally completed in the late 1990s. Putting the Electronic Road Pricing system into force required amendments to the Road Traffic Act. In moving the Bill, then-Minister for Communications, Mr. Mah Bow Tan, remarked (Singapore Parliamentary Debates, 1998):

> [The] ERP system will make motorists more aware of the cost of road use. It will encourage motorists to choose the most optimal time, route and mode of transport for their journeys. The result will be a reduction in the number of trips made by private vehicles, more efficient use of our roads, smoother flowing traffic and less pollution. As the roads become less congested, we can review our vehicle quotas and, if feasible, release more COEs. Together, ERP and the Vehicle Quota System will provide a long-term sustainable and effective framework for managing the traffic on our roads.

The imposition of Electronic Road Pricing in 1998 was therefore sweetened to the motoring (and aspiring to motor) public as a necessary restraint to allow the Government to relax tight control over vehicle ownership quotas. In addition to grand political strategy, implementation of the ERP was smoothened by lowering the initial road prices charged below that of the ALS daily license fee of SGD 3.00. Initial ERP prices ranged instead from SGD 0.50 to SGD 2.50 (Chin, 2002). This was, in any case, consistent with the economic logic of the ERP being a single-entry marginal charge, whereas the ALS was effectively a multiple-entry day license. Since ERP prices were a marginal charge for a single entry, the congestion contribution associated with that entry should be lower, and hence, the charge could be lowered, particularly at shoulder periods where the ERP system had the flexibility to vary pricing almost continuously. In addition, taxes on vehicle ownership were restructured to mitigate concerns that ERP implementation would result in a net increase in the costs of motoring.

Expansion of Electronic Road Pricing and proposals to shift vehicle controls from ownership to usage restraints

In the mid-2000s, the ERP system was progressively expanded beyond the Central Business District (location of the original ALS) and the near-city expressways. The time period charged also expanded, with the introduction of tolling on expressways exiting the central area for home-bound travel during the evening peak. These expansions naturally elicited concerns from the motoring public, who were now joined by retailers opposing the expansion of the ERP to the Orchard Road shopping district. Policy makers addressed these concerns by reiterating the central role of the ERP system as a policy mechanism that could, when sufficiently mature and expanded to encompass more of the road network, gradually allow for shifting of vehicle charges from ownership to usage restraint, thereby granting policy makers more latitude to expand the car growth rate (Ministry of Transport (MOT), 2005).

This point was made by the Ministry of Transport in the Addendum to the President's Address on 15 January 2005:

> To better manage the demand and usage of vehicles, we are also planning to shift the balance from ownership costs to usage costs such as congestion pricing. Congestion pricing will help to relieve choke points and encourage more optimal usage of the road network, thereby ensuring that our roads remain free-flowing even as more Singaporeans are given the opportunity to fulfil their aspirations to own cars. To achieve this, we would need to consider expanding the existing ERP cordon to other areas and times of the day, where traffic conditions warrant. (MOT, 2005)

Forgoing car ownership in favour of "car-lite" urban mobility

In recent years, policy makers appear to have cooled on the political strategy of shifting vehicle costs to usage controls as a mechanism for expanding access to car ownership. While it is unclear why this shift in strategy has taken place, plausible reasons could be that planning projections for a larger population in Singapore – combined with the realities of still-fixed land size – mean that the day when expanded vehicle ownership is no longer possible without creating either unacceptable levels of congestion or island-wide road user charging was fast approaching.

The emphasis has shifted towards public transport, accessibility, and "car-lite" urban mobility, exemplified in the Land Transport Authority's "Walk, Cycle, Ride" campaign, launched in 2016 at the start of the new term of Government (MOT, 2016; LTA, 2016); the Government then explicitly stated for the first time that "Our aspiration is for walking, cycling, and riding public transport to become the way of life for Singaporeans." (MOT, 2016). As a complement to this policy, the car growth rate through the vehicle quota system was cut to 0%in February 2018 (LTA, 2017); the car growth rate is projected to remain zero through January 2022. Additionally, subsidies for public transport have risen significantly, as the public bus and mass rapid transit rail system have been restructured following service and quality shortfalls in the early 2000s. Future policy makers in Singapore, therefore, will no longer be able to use the carrot of expanded car ownership to justify the stick of expanded road pricing controls, and must find new political strategies that resonate with the public to continue expanding road pricing.

Legislative basis for road pricing in Singapore

Road pricing systems (RPS) in Singapore are implemented as subsidiary legislation under the Road Traffic Act (RTA), which grants broad powers to the Minister for Transport to determine rules to regulate traffic. As such, they do not require express Parliamentary approval for implementation, extension and revision (including pricing changes) and there is no independent regulatory mechanism overseeing road pricing. However, because all road pricing rules are enacted as subsidiary legislation, all changes, including pricing adjustments, must be published officially in the Government Gazette prior to implementation and presented (pro-forma) to Parliament at the next available opportunity.

The first congestion charging scheme, the Restricted Zone and Area Licenses Scheme, was implemented on 2 June 1975 (S.L. 38 of 1975) under Section 70 and Section 90 of the Road Traffic Act. There is no record of any road-pricing specific amendments being made to the RTA to allow for the ALS to be implemented. Rather, it seems the authorisation to do so comes from the powers reserved under the RTA for the Minister to make policies as supplementary legislation to regulate road traffic. The Restricted Zone was defined to encompass the downtown core of the Singapore Central Business District and largely conforms to the present-day CBD Electronic Road Pricing region. The initial daily charge was set at SGD 3.00, payable by all private passenger cars entering the zone from 7.30 am to 9.30 am from Mondays through Saturdays, except public holidays. High-occupancy passenger cars (with at least four persons) were initially excluded from charges, as were other types of motor vehicles. The ALS continued in force, with periodic amendments that generally extended the hours of operation, abolished exemptions for most types of vehicles including carpools, and varied daily charges, until 1 September 1998 when it was revoked and replaced by the Electronic Road Pricing System. Chin (2002) provides an excellent overview of the major policy changes to the ALS.

Prior to revocation of the ALS, the Road Pricing System was implemented on 1 June 1995 (S.L. 91 of 1995) under Section 119 and 140 of the Road Traffic Act. The key enabling statute is Section 140, which allows the Minister to "make rules for any purpose for which rules may be made under this Act and for prescribing anything which may be prescribed under this Act and generally for the purpose of carrying this Act into effect and in any rules made by him may prescribe penalties (not exceeding those provided by section 131) for any breach or failure to comply with any such rules." The RPS was implemented to provide for an additional daily charge of SGD 1.00, payable by all motor vehicles except public service vehicles, to enter the East Coast Parkway at specified entry points between 7.30 am and 8.30 am on weekdays. The RPS was expressly designed to work in tandem with the ALS and was designed to control traffic congestion along the major expressways leading to the city. A valid Area License to enter the CBD entitled the motorist to use RPS-priced roads without purchasing an additional RPS license, but not vice versa. Amendments to the RPS adjusted the timing of restricted hours, the charges payable and the entry points or roads chargeable. The RPS was revoked on 1 September 1998, and like the ALS, was replaced by the Electronic Road Pricing System.

The Electronic Road Pricing System was implemented in September 1998 (S.L. 78 of 1998) under Section 34D and 140(1) of the Road Traffic Act. Unlike earlier congestion management schemes, the Road Traffic Act was specifically amended with effect from 1 August 1998 to allow for the ERP to be implemented (Act 5 of 1998). The amendments under the new Part 1A, Sections 34A-34E, introduced the concept of road-user charges for the first time, defined as "the charge payable for riding, driving or moving a motor vehicle on a specified road during the prescribed hours" (Act 5 of 1998). Part 1A grants broad authority to prescribe the time, place, and amount of road-user charges to be paid, as well as to regulate the technologies and devices used to assess and collect road user charges, and to enforce violations.

The legal requirements under the ERP System, including the requirement to have an in-vehicle unit installed in all motor vehicles entering priced roads, the mode of payment through stored-value cashcard, are specified solely in the subsidiary legislation, including the penalties for non-compliance. As part of the subsidiary legislation, a Schedule is published setting forth the specified roads where road user charges are payable, the times of the day and week where charging is in force, and the charges levied for each specified type of vehicle. Amendments to the subsidiary legislation are published any time the location, amount, and timing of road charges are varied.

As of 2020, there are no subsidiary legislation or legislative amendments that have been publicly disclosed concerning the adoption of the GNSS ERP. Based on the Road Traffic Act as of 2020, the existing Part IA, Sections 34A-34E on Road-User Charges appear to allow for a GNSS system without further amendment, as the legislation specifies that any appropriate “electronic or computerised or other facilities” may be installed on roads for the purpose of collecting road-user charges, and vehicles may be required to install any “devices and appurtenances” to be allowed to drive on charged roads. While the legislation does not specifically authorise road-user charges based on distance (Section 34D states that charging may vary depending on the road, timing, and type of vehicle), it also does not specifically prohibit distance charging.

The GNSS ERP system allows for more complex charging mechanisms that depend on the vehicle-distance travelled within the charging zone; charging rates may also vary based on contemporaneous congestion levels (as with hight-occupancy toll (HOT) lanes elsewhere) and even the charging zones themselves may be flexible, as relocating the zones would not require fixed charging infrastructure (subject to accuracy limitations in built-up areas). It is unclear whether the current legal framework for road pricing allows for dynamic changes to pricing and areas covered. As explained above, every road price adjustment is currently published as supplementary legislation, which does not accommodate dynamic price adjustments. While charges can be published as pricing formulas (as is done for computation of road tax, which is based on a sliding formula dependent on the engine capacity and type of vehicle), more complex algorithms could be challenging to publish as plain text. This may limit pricing policy implementable under the GNSS ERP unless the primary legislation is changed to allow for more flexible pricing methods. This may also explain why, thus far, policy makers have not considered or experimented with real-time dynamic pricing mechanisms, as these could require changes to the primary legislation to be implemented. It is not likely as of September 2020 that the Singapore Government would face significant opposition to passing the necessary legislative amendments (due to having a solid majority in the legislature), but the political costs of having to debate and pass legislation are significantly higher than formulating and presenting subsidiary legislation, creating some policy inertia.

Technical development of the next-generation Global Navigation Satellite System-based ERP

Planning for Singapore’s next-generation Electronic Road Pricing system started soon after the launch of the first generation, gantry-based system. Then-Senior Minister of State Khaw Boon Wan, in his opening remarks at the 5th International Conference on Intelligent Transportation Systems in September 2002, noted that a consortium led by National Computer Systems, a Government-linked company, was “busily developing the technology for the next version of the ERP”. Early-stage field trials in Singapore of a GNSS ERP system by the first-generation ERP developer, Mitsubishi Heavy Industries, took place during the 2000s (Ohno et al., 2007).

The System Evaluation Test (SET) for the GNSS ERP system took place over 18 months from 2011 to 2012, concluding in December 2012. The SET established proof of concept and demonstrated the technical capabilities of potential system vendors. On 1 October 2014, the Singapore Land Transport Authority called a tender for the development of a GNSS ERP system (LTA, 2014). Three consortia were shortlisted for participation: NCS Pte Ltd & Mitsubishi Heavy Industries Engine System Asia Pte Ltd (NCS-MHI); ST Electronics (Info-Comm Systems) Pte Ltd; and Watchdata Technologies Pte Ltd & Beijing Watchdata System Co Ltd. The tender was awarded on 25 February 2016 to the NCS-MHI consortium at a development price of SGD 556 million. The tender took place using a two-envelope process with equal weightage to price and quality; the NCS-MHI consortium submitted both the lowest bid price and the highest quality bid. The tender has no private financing or partnership component. Hence, the Land Transport Authority/Singapore Government has full rights to levy and adjust charges and to collect revenue.

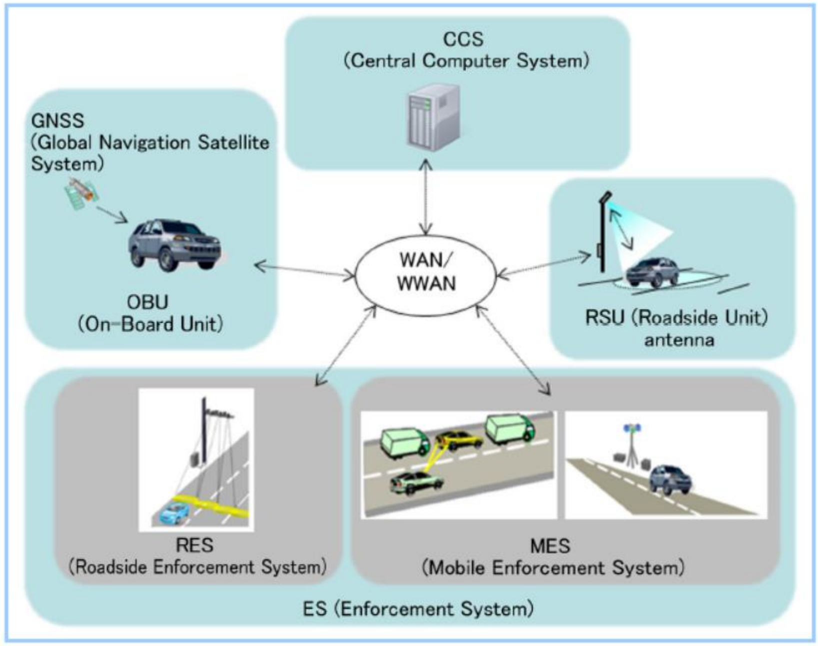
While there are no publicly released technical documents on the GNSS ERP issued by the Land Transport Authority, Mitsubishi Heavy Industries published a report detailing the 2012 System Evaluation Test (Hiura et al., 2013). The SET demonstrated that vehicles equipped with the GNSS ERP system were able to levy the appropriate charge within 12.5 metres of passing or approaching the designated charging point under a wide variety of conditions, including suburban travel, expressway driving, and driving in built-up areas. Under most conditions, vehicles equipped for the GNSS ERP system levied the charge within 2.5 metres of the designated point nearly half the time (Hiura et al., 2013).

GNSS ERP system architecture

The GNSS ERP system consists of five networked components, shown in Figure 3: An onboard unit in each vehicle, a central computer system, a roadside unit antenna, and a mobile and roadside enforcement system. The technology and systems network is similar to that of the heavy goods vehicle distance-based tolling system in place in Germany since 2005; however, the key challenge in urban areas is reduced GNSS accuracy (Ohno et al., 2007), which had to be specifically overcome through developing and building out roadside infrastructure.

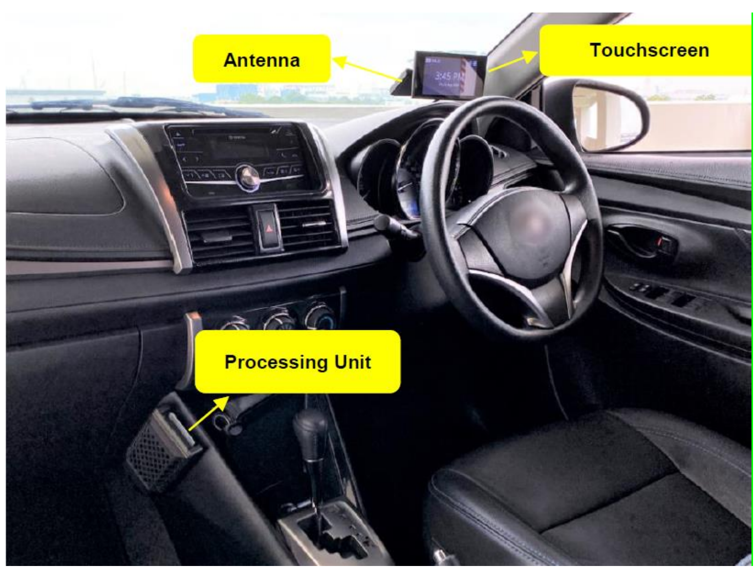
The on-board unit (OBU), shown in Figure 4, determines the location and movement of the vehicle, using a combination of the GNSS signal, internal sensors, and predictive algorithms. The OBU then determines the appropriate charge to levy, based on vehicle location and movement, mapping data, and the current schedule of charges. The OBU also displays to the motorist relevant information about charge payment. The OBUs accept the same payment cards/payment systems as the existing ERP in-vehicle units, including account-based billing (LTA, 2020). The OBUs also include Dedicated Short Range Communications (DSRC) capability, which supports legacy ERP applications such as automated car park entry/exit charging (LTA, 2020).

Figure 3. Component architecture for Global Navigation Satellite System Electronic Road Pricing system



Source: Hiura et al. (2013).

Figure 4. Onboard unit for Global Navigation Satellite System Electronic Road Pricing system



Source: Land Transport Authority (2020).

Since the OBU is a general-purpose navigation and computing device, it supports additional value-added services such as traffic information, parking payment, and activation and payment of off-peak or restricted-use vehicle licenses (LTA, 2015). As of September 2020, however, the only confirmed plan for value-added services are that traffic updates and location-specific safety warnings such as for School Zones will be pushed to the OBUs (LTA, 2020).

Because GNSS has reduced accuracy in built-up areas, due to satellite signal reflection from tall buildings, or obstructions from terrain or infrastructure such as viaducts, Roadside Units (RSUs) must be deployed to augment the GNSS signal. The RSUs improve accuracy and serve as communications nodes for the system. No information is available on the number of RSUs deployed, although it seems probable many of the existing ERP gantries located within the central business district (CBD) will have to be replaced with RSUs to maintain charging accuracy, since these gantries are often surrounded by tall buildings or must discriminate between traffic flows at key junction points.

The central computer system (CCS) co-ordinates information with the other subsystems. In particular, the CCS receives data from OBUs on charges levied and updates OBUs with new road charging schedules. However, based on the Mitsubishi Heavy Industries design, the CCS does not need to compute the appropriate charges for the vehicle, as that functionality is carried out by the OBU (Ohno et al., 2007). The CCS is also capable of pushing traffic information to OBUs, via RSUs, to support motorist guidance functions.

Finally, the enforcement systems, consisting of fixed roadside monitoring and mobile vehicle-mounted monitoring, use DSRC signals to check passing vehicles for the presence of a working OBU with a valid payment account. Violators are identified using automatic number plate recognition systems. It should be noted that in Singapore, installation of the existing ERP in-vehicle units is mandatory for most registered vehicles, and this practice will continue for the new GNSS-enabled OBUs.

As of September 2020, citing global supply chain disruptions due to Covid-19, the Land Transport Authority has pushed the full implementation date for the next generation GNSS ERP system to 2023. Installation of OBUs to replace existing in-vehicle units will take place from the second half of 2021, over a period of 18 months (LTA, 2020). There is no present urgency to substantively expand the congestion charging framework, as traffic volumes are significantly below pre-Covid-19 peaks, resulting in a widespread reduction of ERP charges throughout the entire network.

Privacy concerns with the transition to GNSS ERP

Concerns about motorist privacy under Electronic Road Pricing have been raised periodically, including at the debate on amendments to the Road Traffic Act authorising the ERP. In response, the then-Minister for Communications stated that the road charge payment method – which requires a prepaid Cashcard to be inserted into the in-vehicle unit – was designed to avoid retention of motor vehicle identification data (which would be required under an account-based billing system). In the initial design, only vehicles committing violations would be recorded by cameras and their identification retained until the offence was dealt with (Parliament of Singapore Debate 19 February 1998, Cols 374-378).

The GNSS ERP system naturally raises more privacy risks than the existing ERP system, which can feasibly only track vehicles passing through specific fixed gantry points. The GNSS ERP system is presumably capable of tracking vehicles anywhere in Singapore or even abroad since the OBU continuously tracks vehicle location data. In response to questioning from Members of Parliament on motorist tracking under the GNSS ERP, the Singapore Government has committed in multiple Parliamentary debates to use the traffic location data from the GNSS ERP only in an aggregated format.

Privacy concerns may be more heat than light. Motorists in Singapore have widely adopted a mobile app-based car parking payment system, known as *parking.sg*, which has been available since October 2017. It requires users to specify the location and registration plate of their car to make proper payment. In addition, ERP regulations have been adapted to allow account-based billing through credit/debit cards or bank facilities on an opt-in basis (S.L. 93 of 2015).

Preliminary review of the GNSS ERP System

While it is premature to assess the technical merits of the GNSS ERP system, it is worth recalling some of the GNSS ERP's key development objectives, and to tentatively discuss whether they are likely to be met in practice.

The most important reason why Singapore policy makers invested in developing a GNSS ERP was the expectation that operating costs would be lower, and deployment flexibility would be greater, under GNSS. It was expected that GNSS would obviate the need to install fixed roadside gantry infrastructure – which took up land space and was unsightly – to facilitate road charging. Instead, the GNSS ERP system could be simply expanded via software to define new virtual charging zones or price schedules. In addition, policy makers had expressed concerns that the existing ERP infrastructure relied on proprietary technology, increasing maintenance and operating costs: a GNSS system, if it relied on open source technology, would reduce such costs.

However, it is not clear that either of these technical development goals has been met, and if so, to what extent. The technical papers by Mitsubishi Heavy Industries, the GNSS ERP system developer, note that GNSS location services that rely on satellite signals alone are not accurate enough in a highly built-up, complex urban area, to allow for road user charging functions with a high degree of reliability. Therefore, GNSS ERP system deployment in any urban context will not simply consist of installing OBUs in vehicles or requiring applications to be installed on mobile phones. Instead, an investment in roadside infrastructure is required to improve accuracy to acceptable levels. This means that there may be substantial marginal and operating costs associated with maintenance and expansion of the GNSS ERP system, although the magnitude of these costs will likely depend on the accuracy requirements and on local urban geography. It has also not been disclosed whether the GNSS system has been able to reduce costs substantively using open source technology.

A second development objective was for the GNSS system to support an ecosystem of connected mobility services for motorists, which would be delivered through the OBUs. These value-added services would have included mobile parking payment, real-time guidance, digital vehicle use licenses, and so forth. These services, particularly if offered by commercial developers, could have potentially served as a revenue stream to offset system costs. However, between the conception of the GNSS ERP system in the early 2000s and the present day in 2020, connected mobility services have become common as mobile phone apps, as well as in newer model cars. The GNSS OBU presents risks of technological obsolescence, as it is essentially a general-purpose mobile computing device and is expected – based on the practice for current in-vehicle units – to last for the typical ten-year lifespan of the car under the Vehicle Quota System. It seems probable that the computing power and features of the average smartphone, or the computer systems installed in new cars, will evolve faster than the OBU technology platform. It is unclear if there will be support for developing value-added features specifically for the OBU system when development costs will likely be lower for common mobile phone platforms or car computing platforms. Early critics of the GNSS ERP system have already suggested that the OBUs could be replaced by motorists' mobile devices, and the Government has indicated that this possibility will be looked into (Yong, 2020).

Economic effects of road pricing in Singapore

> Each additional car coming on the road adds to the congestion for all other motor vehicles already on it. This is particularly so during peak hours when large numbers of motorists travel along the same roads to the same places at the same time… (Road Transport Action Committee, 1974)

The socially optimal road user charge is deceptively straightforward: It is equal to the marginal social cost imposed by the marginal driver, at the socially optimal volume of traffic. The difficulty lies with determining the structure of the demand and social marginal cost curves for driving, which are required to estimate the socially optimal volume of traffic. Additional considerations, including effects on the traffic network from time or travel route shifting, pecuniary externalities on businesses catering to motorists, and demand and cost heterogeneity between motorists and different types of traffic, make estimating an exact solution an intractable task.

As the quote from the 1973 Road Transport Action Committee indicates, the planners understood the theory, and likely, many of the complications involved with optimal road pricing. This may explain why in practice, congestion pricing policy in Singapore has been based on targeting road speed bands to achieve maximum traffic flow, through iterative price and policy adjustments, rather than any attempt to estimate traffic demand or social marginal costs.

The design and effect of the Area License Scheme 1975

The Road Transport Action Committee, which formulated the Area License Scheme, assessed that approximately 28 000 private cars entered the Restricted Zone from 7.30 am to 9.30 am daily at end-1973; about half were estimated to be work commuters. The RTAC aimed to remove about half of the car commuters – 7 000 private cars – through the Area License Scheme and associated measures, for a total private car traffic reduction of about 25% from the peak.

However, the ALS, which charged SGD 3.00 per day initially, had a larger than intended effect on traffic (Phang and Toh, 2004). During the Restricted Hours of 7:30 am to 9:30 am, daily passenger car traffic entering the Restricted Zone fell from 32 421 to 7 727 after implementation – a drop of 76.2%, or a reduction of car traffic from about 8 105 per half hour to 1 931 per half hour. While some spreading of passenger car traffic occurred, this resulted in the shoulder periods before and after the Restricted Hours seeing considerably more car traffic, with car traffic from 7:00 am to 7:30 am increasing from 5 384 to 6 565, and from 9:30 am to 10:00 am increasing from 7 059 to 7 479.

Economists generally concluded that the ALS charges were too high to be optimal. Besides significant trip retiming to the shoulder periods (which became nearly as congested as the former peak period), roads that bypassed the Restricted Zone became congested with former through-traffic, and there was also some evidence of mode shifts to exempt vehicles (Phang and Toh, 2004).

Regardless, policy makers appeared to consider the ALS a success. The Restricted Hours were extended to include the 9:30 am to 10:15 am shoulder period, and the ALS charges were increased progressively to SGD 5.00 by 1980. Traffic levels during the morning peak remained significantly below the pre-ALS level well into the 1980s: while 74 000 vehicles entered the Restricted Zone daily in March 1975, prior to the ALS, an estimated 51 000 vehicles entered daily in 1988. These traffic reductions clearly continued to exceed the RTAC's original targets, suggesting that the implicit objective may have been to achieve free-flowing traffic within the Restricted Zone, rather than a specific reduction in traffic volume.

Further revisions to the ALS in the late 1980s and early 1990s greatly expanded the scope of chargeable vehicles (exempting only public service vehicles) while reducing charges back to SGD 3.00. All-day charging was implemented including for the evening peak hours, with a discount for part-day licenses usable for the intra-day period. In 1995, the Road Pricing System was introduced, which required motorists using the East Coast Parkway, a heavily congested expressway, to purchase a license to enter the expressway during peak hours.

A number of papers have examined the effects of the Area License Scheme: Phang and Toh (2004) provide a review. The general consensus appears to be that the ALS charges were higher than optimal, considering the excessive time-, mode- and location-shifting behaviour by motorists, and the underutilisation of Restricted Zone roads. Wilson (1988) argues that once scheduling costs are considered, the ALS resulted in a reduction in welfare.

The design and effect of the Electronic Road Pricing System 1998

The Electronic Road Pricing System replaced the existing pay-and-display based Area License Scheme and Road Pricing System in September 1998. Besides obviating the need to distribute printed licenses and to conduct manual enforcement, the ERP crucially allowed policy makers to charge time-, location-, and vehicle type- varying tolls on a marginal usage basis. While there was already variation of tolls under the ALS and RPS, this was hindered by the fact that each separate toll charge required the design and distribution of a new printed license. The ALS and RPS, moreover, had no capability of charging tolls on a marginal usage basis, because toll gates had never been contemplated (likely due to the land take requirements and traffic congestion they would have generated).

For the first year of operation, the ERP simply replaced the existing road charging schemes with no change in the coverage area. However, the toll schedule was adjusted to allow for tolls to progressively ramp up and down during the morning and evening peaks, and tolls were also reduced to reflect application as a marginal usage charge, rather than as a multiple-entry pass. Under the existing ALS, the license charge for entry from 7:30 am to 9:30 am was SGD 3.00 (which also entitled the user to multiple entries throughout the rest of the day); the ERP replaced this with a charge that ramped up in SGD 0.50 increments every half hour, starting at SGD 2.00 at 7:30 am, rising to a maximum of SGD 3.00 from 8:30 am to 9:00 am, and then falling to SGD 2.50 at 9:00 am.

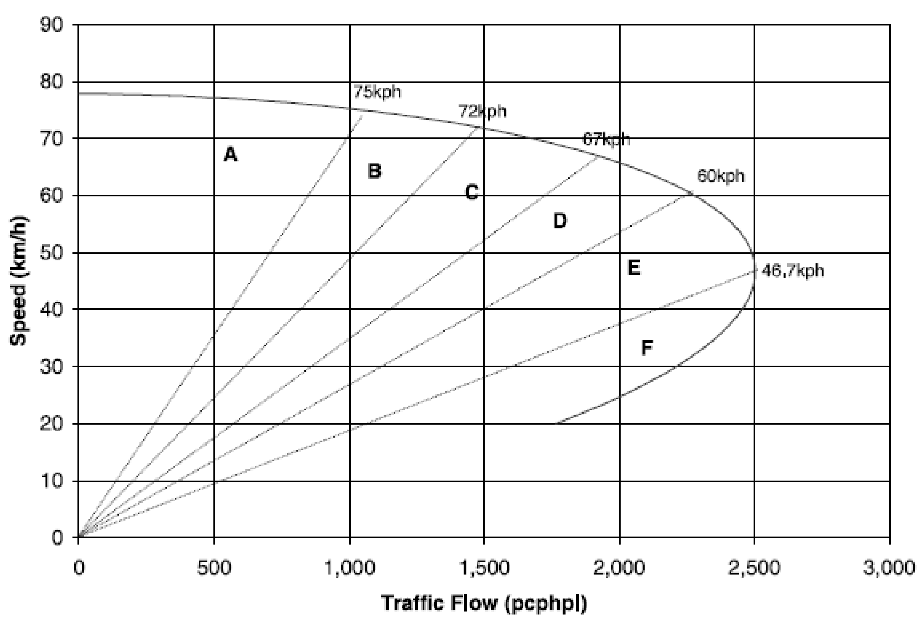
The change in tolling mechanism alone – from multiple-entry license to marginal use charge – appears to have resulted in a traffic reduction of 10-15% in the Restricted Zone immediately following the change to ERP, even though tolls were reduced (Chin 2002; Phang and Toh 2004). Besides the reduction in traffic levels, ERP also allowed for more effective peak spreading of traffic because the tolls can be progressively increased and reduced ("shoulder-charging") in accordance with time-specific travel demand This peak spreading behaviour has been captured in discrete choice models of motorist response to ERP by Olszewski and Xie (2005) and Xie and Olszewski (2011).

The effect of point-based tolling to use a road or enter a district cordon has been fairly well studied, albeit with data limitations. Studies on Singapore include Chin (2002), Phang and Toh (2004), Olszewski and Xie (2005), and Xie and Olszewski (2011); on London include Leape (2006), Prud'homme and Bocarejo (2005); on Stockholm include Börjesson et al. (2012). The literature on Singapore's road pricing finds that when variable-rate shoulder to peak pricing is employed, peak spreading results, with motorists redistributing their time of travel to the shoulder periods where charges and traffic volumes are lower. The Singapore evidence also finds that price elasticity of demand varies by vehicle type and by tolling location, with private passenger cars tending to exhibit higher price elasticities of demand than goods vehicles, and with elasticities being higher for expressway tolling than to enter the central business district tolling cordon.

Policy makers have been able to use the pricing flexibility inherent to the ERP system to habituate motorists to periodic price revisions, which are made on a quarterly basis or in response to extraordinary events (during the Covid-19 crisis, ERP tolls were lowered to SGD 0 for several months due to the reduction in traffic). These price revisions allow policy makers to optimise traffic flows without using explicit models of traffic demand, through applying iterative price adjustments to maintain traffic flows within optimal speed-flow ranges of 45 kph – 65 kph on expressways and 20 kph – 30 kph in the central business district and arterial roads (Chin, 2002).

While economists might expect that optimal pricing requires some estimate of the traffic demand function, private travel cost function, and marginal social cost function, Li (2002) argues that the optimal toll charge can be approximated without knowledge of the traffic demand function. The standard congestion externality model can be adapted to view the socially optimal traffic volume as a function of traffic speed on Singapore roads, following the speed-flow model. The key insight is that the socially optimal traffic volume must lie in the region between the maximum traffic flow and the maximum road speed. According to Li, the speed-flow relationship estimated by Mak (1997), shown in Figure 5 is the basis for LTA's iterative pricing management strategy. The ERP toll is set based on targeting traffic flows at levels of service D and E, with the objective of preventing deterioration to F, where both speed and flow are reduced.

Figure 5. Speed-flow relationship for Singapore expressways



Source: Li (2002)

Although LTA has generally not published technical information on how ERP charges are determined, LTA staff have publicly acknowledged that ERP speed band targeting is based on maximising traffic flow based on the speed-flow relationship established for Singapore roads (Chin, 2002).

The ERP system performs well at producing high average road speeds. From 2005 to 2014, the average peak-hour speed on Singapore Expressways and the CBD/Arterial Roads ranged from 61.2 kph to 64.1 kph, and from 26.6 kph to 28.9 kph, respectively. This is remarkable, given that private car numbers increased from 401 638 to 536 882 during this period, although it must also be noted that continuous road upgrading projects have taken place.

Besides regular ERP price iterations, some policy decisions reveal consideration of other demand and economic factors in ERP pricing policy. There is a scheduled biennial adjustment for cyclical demand shifts during the June and December School Holidays when traffic drops due to lack of school servicing trips and holidays taken by families out of the country. ERP rates are lowered during this period.

In August 2005, ERP was extended to charge motorists for outbound trips on the Central Expressway during the evening peak hour from 6:00 pm to 8:00 pm. In October 2005, an additional ERP cordon was added around the Orchard Road shopping corridor, focusing on reducing afternoon and evening traffic, including on Saturdays.

These ERP extensions proved controversial. Motorists questioned why, having paid to enter the city in the morning, they had to pay road user charges to return home. Retailers in the Orchard Road area, meanwhile, expressed concerns that ERP charges would discourage patronage. In response, policy makers indicated that they would treat evening congestion with more flexibility before raising outbound Central Expressway ERP rates further or extending operating hours, which is consistent with a lower value of time being placed on outbound trips during the evening peak hour, compared to inbound trips during the morning peak. As for the Orchard Road district, policy makers argued that the evidence suggested the main effect of ERP charges there was to reduce through traffic, rather than discourage motorists headed for the Orchard Road shopping malls. The Orchard Road ERP extension, nonetheless, forced policy makers to consider whether the purpose of the trip and the resulting pecuniary externalities on third parties such as retailers should matter for road pricing decisions.

There has been some work done on the effects of the ERP system on urban land-use. Agarwal et al (2015) find using a difference-in-difference approach that the November 2010 ERP rate adjustment, which saw rates rise by SGD 1.00 for the Orchard Road and Bugis-Marina cordons, resulted in an 18.8% relative decline in retail real estate prices in these areas. However, there was no significant effect on residential or commercial real estate. This suggests that while, on net any increases in ERP-related travel costs for residents and businesses might be offset by improvements in traffic congestion, merchants could have valid reasons to be concerned about the effect of road pricing on discouraging motorists from shopping at their establishments.

Road prices in perspective

Although the road pricing system has been gradually expanded to encompass key expressway and arterial routes in addition to the central business district, road usage charges have fallen in real terms over the years, while incomes have grown rapidly. The initial maximum ALS day license charge was set at SGD 3.00 in 1975, worth about SGD 7.23 in 2019 dollars; the ALS charge subsequently rose to SGD 5.00 in 1980 (SGD 9.55 in 2019 dollars), before falling to SGD 3.00 in 1989 (SGD 4.63 in 2019 dollars). On conversion to the ERP system, the maximum ERP charge to enter the CBD was initially SGD 3.00 in 1998 (SGD 3.74 in 2019 dollars) and has remained close in nominal terms since. Real GDP per capita, meanwhile, is six times higher in 2019 compared to in 1975 – so road user charges for driving into the CBD are more affordable today than they have ever been.

Policy makers have been reticent to discuss revenues from the ERP system, perhaps because the charges are not hypothecated for transport infrastructure or public transport use. There is, hence, little political benefit to discussing road pricing revenues, although the Government when necessary explains that road pricing developments, such as the ERP system upgrade over the ALS, are not revenue-driven. The total amount collected through ERP charges in 2005 was in fact 20% lower than that collected by the ALS in 1997, the last full year of ALS operation , while ERP revenue ranged from SGD 77 million to SGD 86 million per year between 2001 and 2005 (MOT, 2006); revenue has risen to approximately SGD 150 million per year in the early 2010s, following the expansion of the ERP system.

The financial contribution of road pricing systems is minuscule compared to other vehicle-related taxes and charges. In the financial year 2018, the Singapore Government collected SGD 2.623 billion in motor vehicle taxes and SGD 3.616 billion in vehicle quota premiums (MOF, 2020). The combined amount in vehicle-related taxes collected was equal to about half of all personal income tax collections for that year and formed 8.5% of the Government's operating revenue. Indeed, the combined vehicle-related taxes amount to an average of 1.56% of GDP from the financial years 2014-2018 and significantly exceeds the operating expenditure of the entire Ministry of Transport (SGD 1.9 billion), including subsidies for public transport operations which amount to approximately SGD 1.5 billion/year (but not infrastructure development expenditures). These figures do not include excise duties for petroleum products (SGD 784 million, FY2018) and motor vehicle import excise taxes (SGD 486 million, FY2018), which are considered customs duties rather than vehicle restraint based policies.

Considerations for distance-based charging

In early discussions of the next-generation GNSS ERP system, policy makers suggested that distance-based charging could be a fairer, more accurate method of pricing motorists for their actual contribution to congestion, that could also allow for expanded vehicle ownership. One of the concerns with higher vehicle ownership was that congestion would increase in areas outside the reach of the present ERP system or would lead to an endless, costly expansion of the ERP system. Distance-based charging, through a vehicle-based satellite tracking system, could allow for congestion charging to be applied in a wider range of areas than under the gantry-based ERP system, thereby facilitating expanded vehicle ownership. Moreover, vehicle ownership restraints could have been shifted towards usage-based restraints, such as by conversion of the quota system from a time-limited right of vehicle ownership, to a distance or distance-congestion-weighted right of vehicle ownership, as suggested by Barter (2005).

Since then, policy makers have noticeably cooled on the prospects of introducing new methods of road pricing. The most recent news release from the Land Transport Authority has stated explicitly that there will be "no changes to [the] congestion pricing framework" when the GNSS ERP system is implemented (LTA, 2020).

To the best of the author's knowledge, there have been no recent studies conducted that would be informative on the potential methods of charging, or effects of distance-based charging in Singapore. While there are road pricing systems elsewhere that employ some type of distance-based tolling, such as certain HOT lanes in the United States, and highway toll charges for heavy goods vehicles in Germany, there appears to be no applicable experience of using distance-based tolling in an urban environment. This should be a priority for study prior to the implementation of any distance-based tolls.

The author conducted a study commissioned by the Land Transport Authority in the early 2010s on the behavioural effects of different road charging mechanisms. The intent was to establish whether motorists treated the same dollar value charge differently depending on how the charge was presented. For example, an expressway segment two kilometres in length could be priced at SGD 2.00 for passing through a fixed charging point; could be priced at SGD 1.00 per kilometre; or, could be priced at SGD 0.10 per 100 metres. Of course, all three charges are the same, assuming no possibility of exiting the expressway early. Nonetheless, in other contexts, behavioural research has established that the way prices are published and communicated affects decision making.

Based on incentivised stated preference experiments, the author found that fixed-point charging discourages the use of the tolled expressway segment to a greater extent than distance-based charging does. This could be due to the greater salience of a fixed toll, which appears larger. A related issue was whether there would be differences between account-based and instantaneous payment; the present ERP in-vehicle units are designed to give feedback on instantaneous payment, to remind motorists that there is a price to using congested roads. Although the experimental context may not be ideal for testing this aspect, the author found that presenting a summary of recent toll payments made on the subject's account discouraged use of the toll routes.

Conclusion

Singapore's Electronic Road Pricing system is technologically sophisticated, mature, and effective. Travel speeds have been maintained on major expressways and the central business district despite tremendous growth in the vehicle population over time. The next-generation system based on the Global Navigation Satellite System allows for significantly greater flexibility and complexity in pricing, providing more tools for managing travel demand. However, the technological capability to implement advanced forms of road pricing does not translate into the administrative or political capability to do so, and the extent of efficiency gains possible from improved road pricing is unclear.

Despite Singapore's status as a pioneer in road pricing, there has been relatively little research on the effects of road pricing in Singapore, particularly since the Electronic Road Pricing system was adopted. The author of this paper could find no publications commissioned by policy makers that attempt to model or understand the economic impact of Electronic Road Pricing, and there has been little administrative data released to third party researchers on traffic flows over time, let alone anonymised vehicle-specific road pricing transaction data. Basic questions such as whether the iterative speed-flow targeting policy adopted by the LTA results in optimal outcomes have hardly been investigated.

The next generation of transport policy makers in Singapore have more policy options than ever before to manage traffic demand. Road charges can potentially be varied by distance, time of day, location, and type of vehicle. The general-purpose On-Board Units, moreover, could be used to communicate with and guide motorists, providing an additional behavioural tool to complement prices. However, little is known about how motorists might respond to distance-based charges in an urban environment (as opposed to highway toll road); whether the format and communication of road user charges matters; and whether the welfare effects differ depending on the location and type of travel that is affected by congestion charging. More research on congestion charging in Singapore and elsewhere will provide policy makers with the confidence to experiment with and adopt new strategies to manage traffic.

Notes

1 GDP per capita figures are from World Development Indicators, various years.

2 Passenger car figures are from Registry of Vehicles and Land Transport Authority, various years; Population figures are from World Development Indicators, various years.

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Congestion Control in Singapore

This paper reviews the development and implementation of congestion control policies in Singapore since the introduction of the Area Licensing Scheme in 1975. It examines the city state's experience of vehicle quotas, cordon charging and electronic road pricing. It also looks at developments in public transport and urban planning to improve accessibility and congestion control. Both public attitudes to congestion policies and their economic effects are discussed and analysed.

All resources from the Roundtable on Congestion Control Experiences and Recommendations are available at: www.itf-oecd.org/congestion-control-experience-recommendations-roundtable.

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