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Parayil, Govindan; Yeo, Tien Ee Dominic

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More than Electronic Toll Booths: Singapore's Electronic Road Pricing Innovation

GOVINDAN PARAYIL & TIEN EE DOMINIC YEO

Abstract *This paper explores the dynamics of the Electronic Road Pricing (ERP) innovation in Singapore, tracing its implementation to subsequent diffusion to delineate the links between technology and society. The ERP system, introduced in 1998, is an elaborate and sophisticated toll collecting system using ICTs to regulate road usage. We use the actor–network theory (ANT) as a conceptual tool to analyse the dynamics of this innovation. Through a detailed examination of both human and non-human actors, we are able to analyse how interests of heterogeneous members of a societal network can be aligned to introduce a technological innovation. In the process, we have observed issues arising from the differential power relationship that exists between road users and government planners as well as the integration of the social and technical aspects of this emerging socio-technological system. As an emergent technology, the ERP innovation system reflects the social morphology of Singapore as it plays out its part in the making of this nascent nation.*

Keywords: Electronic Road Pricing (ERP); ICTs; technology and society; technological innovation; diffusion of innovation; actor–network theory

Introduction

A first time visitor to Singapore would be puzzled or perhaps dazzled by the array of gadgets in any taxi that he/she would normally take from the city state's modern and efficient international airport to his/her destination on the island. Taxies in Singapore have some of the most advanced electronic booking systems using global positioning system (GPS) transponders and information and communications technologies (ICTs), credit card fare collection facility and cellular phones. Also on top of the dashboard is a device for electronically paying tolls (without stopping or slowing down the vehicle) when the taxi passes through the Electronic Road Pricing (ERP) gantries erected on the congested roads and expressways in and around the city centre. Many states and cities use various types of toll collection systems to charge motorists for the use of particular roads, bridges, and tunnels.

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London, for example, recently introduced a £5 daily 'congestion charge' to motorists who want to enter central London. London's partially automated road pricing has been touted as a great success by its mayor.[1] However, few are as fully automated and extensive as the Electronic Road Pricing (ERP) innovation system in Singapore, which is considered a great 'success' by its government.[2]

In this paper, we explore the links between technology and society through a detailed exposition of the development and diffusion of the ERP technological system in Singapore. To do so, we have chosen to examine a situation where an innovation was introduced to overcome existing problems within the transport system, which involves multiple agents—government, private automobile dealers, and a wide array of road users. We will adopt the constructivist framework of actor–network theory[3] to show the 'seamless web'[4] of social and technical actors and processes involved in the development and diffusion of this technological innovation. We use actor–network theory or ANT fully cognisant of its limitations.[5] We use it because unlike other theories ANT helps us to problematise the translation of the ERP technological system within the context of Singapore's communitarian political ideology.[6] ANT helps us to reveal the often concealed instrumental rationality of large technological systems that the state uses to project its modern image. That is, the study of the diffusion of this innovation will help us unravel aspects of 'society in the making' in Singapore.[7]

The 'social choice'[8] in the development and diffusion of an innovation, especially one that is capital-intensive and highly expensive to develop and diffuse such as the ERP system, depends not only on its technical and functional excellence, but also on the differential power relationship between the various actors involved in its shaping. However, unlike the broad interpretative flexibility of technologies that Pinch and Bijker[9] attribute to the users, interpretative flexibility of large infrastructural innovations to the users is often limited to the rate of its adoption (such as rate of enrolment in the innovation network) and little else. Usual concerns like acceptability and adaptability of the innovation by the users tend to be pre-determined because of existing problems within the old system that is being addressed by the new innovation, and hence limited interpretative flexibility is available for the crucial stakeholders of the innovation—the users. The discreetly distributed political power embedded in various technological structures and artefacts[10] during their developmental life-cycle could often be obscured by the feeling on the part of users (of the technology) that they do have a choice and their enrolment in the innovation network (of the technology) is a voluntary act and a marker of their ability to vote with their dollars. This feeling is often misperceived as the freedom that users have in choosing the desired product or service in post-industrial societies that are in the throes of a paradigm shift in their economic mode from production to consumption.[11]

The notion that users always enjoy immense power to shape innovation trajectories is contestable. In modern urban habitats where one has made a conscious decision to locate due to factors related to business or career, one would have little choice but to co-opt most urban innovations as a trade off she has to make in order to be in that urban social space. We will show that the ERP innovation system is one such case where the adopters have limited choice in shaping its technological trajectory. However, we will show instances of resistance shown by many adopters which include some flexibility to interpret the technology. Consequently, the ERP system renders itself as an interesting episode in social studies of technology. Also, as an 'emergent phenomenon'[12] the ERP system is more than a sum of its various

elements. The ERP innovation system reflects the social morphology of Singapore as it plays out its part in the making of this nascent nation.

Background to the Implementation of the ERP

Singapore is a small island city state with a high population density. More than 4.6 million people live in a land area of 682.7 square kilometres.[13] Land has become, invariably, a scarce resource and the city state claims it could ill afford to allocate large parcels of land for roads and highways. As a result, the Singapore government through its agency, the Land Transport Authority (LTA), claims that it wants to allocate and utilise scarce road space more efficiently. This intention, in turn, seems to have translated into one of the most stringent restrictions on private ownership of cars in the world.

Road congestion is a negative externality that has social and economic costs.[14] Road congestion is like a queue and when queues form, economists argue, markets function less efficiently. Congestion leads to waste of time for road users, and economists calculate the value of time in terms of money. In Singapore, this concept forms the underlying rationale for solving road congestion, an epiphenomenon of rapid industrialisation and economic growth. The problem then becomes the most cost-effective means of placing a premium on time. In transport calculations, time is valued directly according to wages or indirectly using the opportunity cost that people seemingly place on their time. The latter is calculated by two techniques: revealed preference (when people's actual travel choices are analysed) and stated preference (when people are asked to give their opinion on hypothetical transport options). There arise important theoretical and practical problems with such calculations. Some argue that only the time involved in 'productive' trips (such as travelling to work or for business) should be considered or be given a higher value, devaluing other trips. Second, wages vary across social groups. For the implementation of road pricing, one questions the accuracy and usefulness of applying the national average hourly wage rate, since, mainly, vehicle drivers are directly involved. Third, if taxes and fringe benefits such as transport allowances were included, it would lead to a wide variation in the final figures.[15] It also does not take into account collective social values of time and how all activities, regardless of wage levels, interfere with each other. Hence such calculations are highly controversial.

Congestion can be curtailed by both supply-side (by expanding and improving road space) and by demand-side actions (by road pricing and regulation).[16] We have already noted that due to land scarcity, expanding road space (a supply-side option) is not an option for Singapore. Over the years, the over-riding policy of the Land Transport Authority (LTA) has been to limit car ownership through hefty fees on vehicle registration, taxes on fuel, road use fees and vehicle import taxes, and, most importantly, via the quota-based allocation of Certificate of Entitlement (COE) to own vehicles. The COE prices can be more than a third of the actual cost of a private car. A low-end Japanese-made car will cost, on average, about US$40,000, one of the highest, if not the highest, in the world. However, due to the rising affluence of the society, the high costs of owning a vehicle alone have become insufficient to regulate congestion in the transport system in Singapore. As such, there has been a gradual shift of policy towards regulating usage, instead of just regulating ownership of cars. Thus the government through its agency the LTA uses road pricing to regulate key roads and expressways from congestion. According to

the LTA, 'Once the cost of congestion becomes transparent, motorists will be better able to make more informed transport decisions'.[17] But to regulate the usage of roads, it is necessary to introduce a new innovation as existing technologies and systems were not equipped to handle such regulation in an efficient manner, especially on a wider scale when more private vehicles are on the road.

The Need for an Innovative System

Road pricing is not novel to Singapore. As early as 1975, the government had introduced a manual road pricing system called the Area Licensing Scheme (ALS). Under the ALS, the most congested parts of the city were cordoned off and demarcated with overhead gantries at the entry points. Such overhead gantries served no technological detection purpose and were mere signposts. During a stipulated period of time, vehicles that entered the ALS zone had to purchase and display an area licence in the form of a paper disc pasted to their vehicle windscreen. The licences had to be purchased at specially erected sales booths and designated post offices and petrol stations prior to entering the zone. Security personnel were stationed at the entry points to monitor all passing vehicles and record the licence plate numbers of vehicles not displaying the paper discs. By the mid-1990s, the same concept was extended as the Road Pricing Scheme (RPS) to three expressways during morning peak hours and required separate licences.

There were three major problems with this manual road pricing system.

1. The ALS and RPS were labour-intensive and cumbersome to operate and enforce.
2. The manual system was inflexible and highly confusing to both enforcement officers and motorists. This was largely attributed to the different rates levied on different vehicle types and fluctuating rates between peak and off-peak hours.
3. The manual system was unable to control the number of repeat entries motorists could make into the restricted zone, reducing the deterrence effect of charging for road use.

Hence the search for an innovative alternative began when technologies for electronic toll collection emerged. Four types of technologies were initially considered for the ERP system.[18]

1. The first ERP technological system that was considered involved video cameras taking photographs of the licence plate numbers of the vehicles entering the restricted zone and then using an optical character recognition system to read the number plates and sending monthly bills to the owners of the vehicle.[19] This passive technology was not considered because of the problems related to billing and the high transaction cost involved in collecting tolls from errant owners of vehicles.
2. The second ERP system that was considered and dropped was a radio beacon system. It involved radio beacons placed at strategic locations within the restricted zones switching on an electronic in-vehicle unit (IU) in the vehicle and deducting the toll charge from a smartcard (cash card) inserted in the IU when the vehicle left the restricted zone. Enforcement was to be achieved by taking photographs of the licence plates of errant vehicles not using or not turning on the IUs. However, one serious problem with the system was whether

the vehicle should be charged even when it was parked. Enforcement was also found to be difficult to reach 100%.

3. The third ERP system considered was to use global positioning system (GPS) technology and smartcard readers. It was to be similar in nature to the radio beacon system. When the system was mooted, the accuracy of convergence of GPS signals with the demarcated restricted zones was in doubt and hence not pursued further. However, the GPS system is being considered now, an issue taken up in the conclusion.
4. Finally, the ERP system that was adopted involved an overhead two gantry system erected at the entrance to the restricted zone. Details of this ERP system, that came into operation in 1998, are presented below.

How the ERP System Works

The LTA stipulated that all motor vehicles (private as well as commercial) sold in Singapore must have an In-vehicle Unit (IU) attached on the dashboard on the right side of the vehicle in front of the driver. The motorist first inserts a cash card into the IU which checks the health of the IU and the cash card. If everything is in order, there will be a short 'beep' sound and the cash balance of the cash card will be shown on the backlit LCD display of the IU for about 10 seconds. A green Light Emitting Diode (LED) will light up on the IU and remain lit until the cash card is removed. If the system is not working when the cash card is inserted into the IU, an 'Err' message appears on the IU display with a long 'beep' sound and a red LED will light up on the IU.

As the motorist drives the vehicle towards the ERP controlled point, which consists of two overhead ERP gantries, the first gantry recognises the presence of an IU and its vehicle class through a radio signal interface (see Figure 1 for a sketch of how the ERP system works). It will then instruct the IU to debit the cash card with an appropriate amount.[20] This amount is determined from a table of prevailing charges for the various classes of vehicles loaded into the outstation by the computer in the control centre. Between the first and second gantries, the IU debits this amount from the cash card. If the debiting is successful, the second gantry queries the IU and obtains a successful transaction confirmation. A short 'beep' sound is produced and the new cash card balance is displayed on the IU for 10 seconds. If the IU is unable to deduct the amount due to an error in the system or no cash card (or an invalid card) inserted or insufficient balance on the cash card to meet the amount, a long 'beep' sound is produced and the red LED on the IU lights up, displaying an 'Err' message. Meanwhile, the vehicle presence detector (located at the overhead ERP gantries) senses the passage of the vehicle. The antennae at the two gantries, the vehicle presence detector and the IU along with the logic in the local controller (part of the overhead ERP gantries) decide whether a complete successful transaction has been made. In the case of a violation or error, the cameras on the rear of the first gantry will take a photograph of the rear licence plate of the vehicle involved.

A violation occurs when vehicles have no IU, no cash card or an insufficient balance on the cash card to meet the ERP charge. Errors occur when there is a faulty IU, insufficient power supply from the vehicle battery to the IU, faulty cash card and partial communications between the IU and the antennae.

When a photograph is taken, the system attaches information on why it was taken, so that technical errors and violations are differentiated. Errors do not necessarily

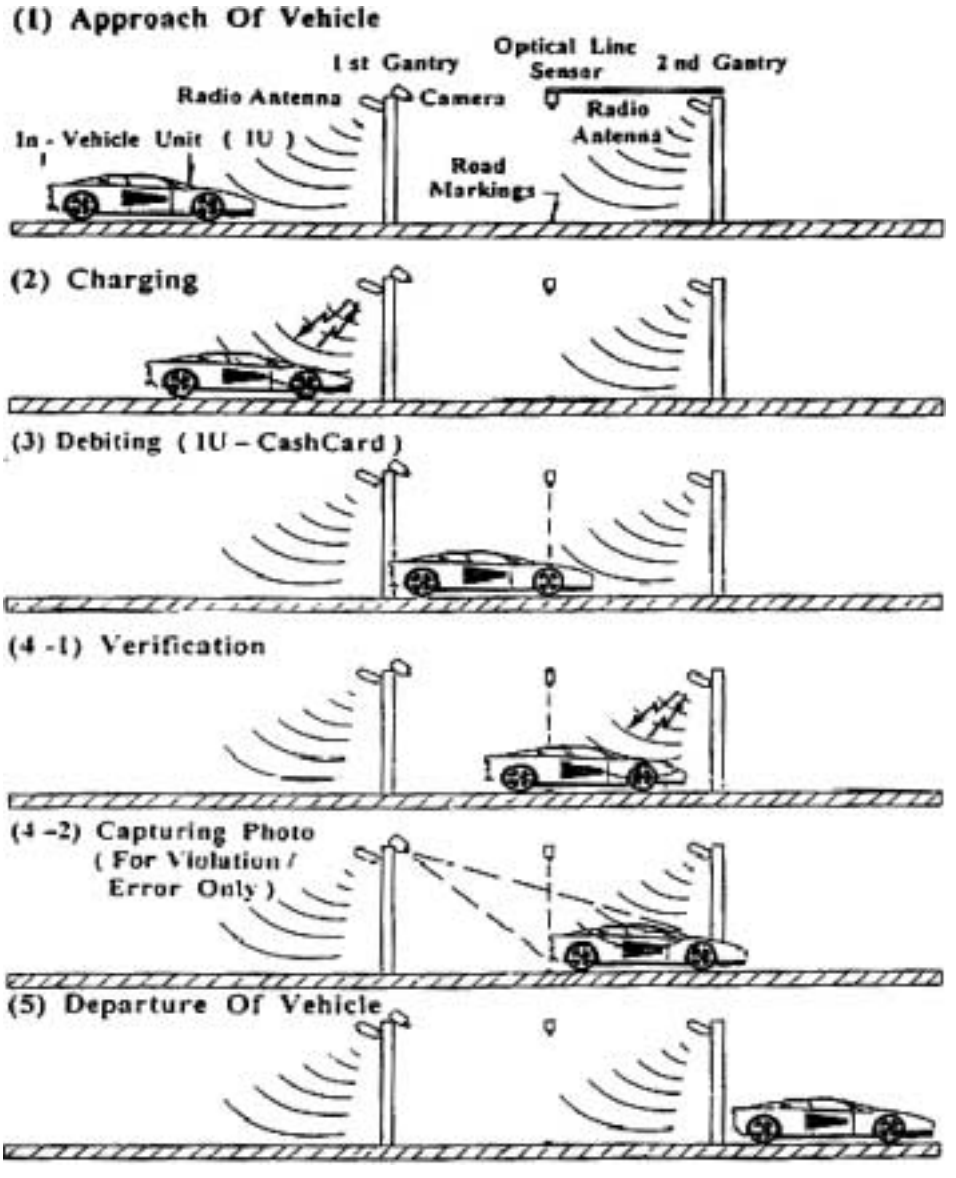

Figure 1. How the ERP system works (source: Menon and Chin, 1998)

result in prosecution of the motorist. The information from the outstations on successful transactions, violations and error records together with photographs are sent periodically to the control centre computers where violations are processed and penalty notifications are sent to the owners of the vehicles through the postal system. A separate control centre monitors the state of all outstation equipment.

In Search of a Theory of Innovation for ERP

Having explained the rationale for the introduction of the ERP innovation and its modus operandi, our immediate task is to select a theoretical framework that can

serve as a conceptual tool to analyse the mode of implementation and diffusion of the innovation. A suitable theory should provide a methodological template to simplify the complex system into its constituent parts. It should also take into consideration all relevant actors, be it road users, government planners or the technological hardware involved. The framework must offer the apparatus for us to explore the seamless nexus of humans and technology in a structured and analytical manner. There are possibly several models for analysing the development and diffusion of technological systems like the ERP, such as the Actor–Network Theory (ANT), the Large Technological Systems Theory,[21] the Diffusion of Innovation Theory (DoIT)[22] and so on. These theories do allow us to examine the interaction between agency and structure in the evolving socio-technological system. However, only ANT allows us to bring in the agency of non-human elements in the innovation network, whereas others refer only to the human agents. It does not hold that we should equate the agency of non-humans with humans, just that looking at the problems of material structures without bringing in human agents help us better understand their embeddedness in the socio-technological matrix.

Although DoIT follows mainstream sociological thinking on structure and agency, ANT works as a seamless web of all the heterogeneous actors without bifurcating them into a technological foreground of material artefacts to be analysed within the social milieu of the various ubiquitous actors and their institutions in the background. That is, there is no such thing as a separate society (made up of human agents and their institutions) to be analysed to explain the workings of the artefacts through an indirect attribution of their agency through their inventors, designers, owners and other 'stakeholders'.[23]

ANT describes how various actors with particular interests and capabilities are enrolled into the innovation network.[24] The process of enrolment involves the mechanisms of simplification and juxtaposition of the heterogeneous elements. Simplification is the act of reduction of association on the part of an actor (for example the agent that wants to introduce an innovation) to a few discrete entities out of an infinite array of entities out there. Juxtaposition is the crucial act of positioning an actor next to another actor such that collective and individual objectives are met and the network could be stabilised. Actors will be enrolled to construct common definitions and meanings, define representativeness, and co-opt each other in the pursuit of individual or collective objectives. The actor–network is simultaneously an actor whose activity is networking heterogeneous elements as well as a network that is able to redefine and transform what it is made of.[25] ANT suggests how technology is shaped by human engineers, market forces, cultural trends, consumer preferences, needs and demands. This presents an in-depth perspective to the relationship between human actors and their non-human counterparts. The ANT model of innovation is applicable to successful as well as failed cases of innovation. However, ANT does have limitations as we will discuss in detail later.

The application of ANT involves the enrolment of actors with interests in the network. First, there is a need to have a detailed understanding of the innovation and how it is intended to work. Second, the network is simplified into the human and non-human actors involved. Finally, the interests of the actors in the network will be co-opted and their interests aligned with those of the focal actor. We shall next apply ANT to the ERP system to assess its applicability.

Application of the Actor Network Theory

As mentioned earlier, actors comprise both human and non-human entities that may have their individual objectives and strategic interests. These interests may encourage or constrain the technology. These interests, in turn, transform technological innovation as a dynamic process. Numerous actors make up a network of interests which becomes stable once they are aligned to the technology. This alignment is achieved not only through the enrolment of actors into the network but also through the translation of interests. It would involve, in a semiotic sense, actors acquiring attributes as a result of their relations with each other and aligning their common interests.[26] Here, we have identified and simplified the actors of the ERP network as ERP gantries, cash cards, control centres, IUs, vehicles, motorists and authorities. We shall study the alignment of their interests and their association with other actors in the network.

ERP Gantries

Through the simplification process in ANT, we reduce the various machines, antennae, cameras, sensors and the central computer into a black box called 'ERP gantries'. ERP gantries form the centre core of the network. When the LTA first wanted to implement electronic road pricing, they needed a system that could work with the local conditions and could be customised to fit their own requirements. As such, the enrolment process took place in the form of a tender, which lasted two years, during which three short-listed contenders were paid S$1.5 million each to design a workable sample on an actual stretch of road in Singapore. Substantial testing with real life conditions were carried out for months to ensure that the interests of the other actors were aligned with the ERP gantries. In other words, other actors had to work without conflict with the ERP gantries. For example, the IUs had to be able to communicate with the ERP gantries while the control centres had to be able to receive signals from them.

Control Centres

It would not be accurate to assume that the control centres, despite the name, are the brains of the system. Most of the logic work is executed independently at the ERP gantries. The control centres function as storage and monitoring devices for the ERP gantries. However, the role of control centres in the network cannot be discounted. Control centres play an important part in the enrolment process by ensuring that the system functions properly. In doing so, control centres themselves are aligned to the ERP gantries and check whether the ERP gantries are internally aligned.

Cash Card

The cash card is closely associated with the vehicle, IU and the motorists. Its relation to the network is not limited to being the mode of payment. The wider purpose of the choice of cash card as the mode of payment was part of the government's drive to introduce a cashless society with the use of the cash card as electronic wallets. An active system, which requires the use of the cash card for payments, was considered as a convenient vehicle for the widespread use of the cash card to take off.[27] The

alternative was a passive system in which all transactions would be accumulated and motorists would be billed at the end of the month. To enrol and align the cash card with the vehicle, special heat-withstanding plastic had to be used to ensure that the cash card would not melt after a few hours in a vehicle under the hot sun. Motorists would have to top up the cash card when its balance ran low.

In-Vehicle Unit (IU)

The IU plays the important role of communicating signals between the vehicle and the ERP gantries. It also displays and informs motorists of any errors and the balance of the cash cards. Hence it is important that the IU is properly affixed in the vehicle. In passenger cars, it is attached to the extreme right of the vehicle as that position provides a level of safety for viewing the display and convenience. This helps to align the IU with the interests of the motorists, given that most drivers are right-handed. As the IU requires power to be drawn from the vehicle battery, special modifications had to be made to all vehicles to ensure this process was smoothly executed. A potential conflict may arise if the vehicle windscreen interferes with the ability of the IU to communicate with the ERP gantries. Vehicle providers served the important role of aligning the IU by fixing and testing it.

Vehicles

Technical considerations of the vehicle to align it with the network included the proper fitting of the IU, the re-wiring of the battery to power the IU, compliance of the vehicle windscreen to facilitate radio frequency communication between the IU and the ERP gantries. The vehicle element would also include vehicle providers such as public bus and taxi companies, vehicle mechanics and car distributors to be enrolled to participate in the implementation process of the ERP. Their involvement in the network was mainly to install the IU in their vehicles.

Motorists

To ensure full-compliance, all 680,000 vehicles in Singapore at the time of implementation were issued with free IUs with free installation at their own preferred workshops. Notices to all existing vehicle owners were dispatched way before the implementation of the system to ensure that car owners had sufficient time to install their IUs. All new vehicles were automatically fitted with an IU by the vehicle providers. Motorists were also required to purchase and maintain the balance in the cash card. The simplification process would have also included taxi drivers and drivers who do not own vehicles. A massive publicity drive was conducted by the authorities to educate the general public about the implementation of the ERP. However, actors left out of this network but affected by the ERP include general commuters who stand to benefit if the ERP is successful in reducing traffic congestion as well as business owners who stand to lose if the ERP set up near their outlets deters motorists from shopping or conducting in-person business transactions there.

Authorities

The authorities include everyone from the engineers to policy makers from the LTA, which is the focal actor node of this network. Their decision directly affects

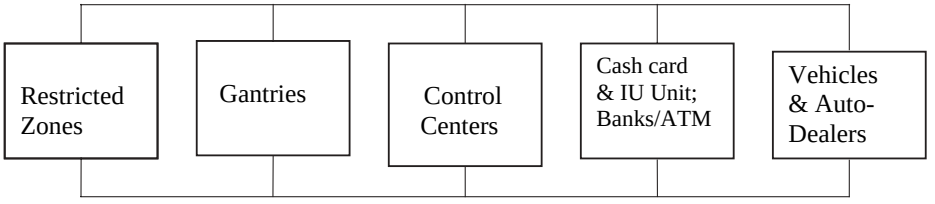

Figure 2. ERP system

all other actors in the network. They are responsible for coming out with ways to ensure that the interests of all the elements are aligned with theirs. As they enjoy unchallenged power in Singapore, often their interests and objectives override all other actors in the network. Nevertheless, they should constantly seek feedback from road users to ensure that the latter's interests and concerns are addressed so that resistance and conflicts could be minimised.

The important structural elements of the ERP system are presented in Figure 2. The actor–network of the ERP innovation system is presented in Figure 3. An important and powerful node in the network is the LTA. What we have sketched here is only a simplified actor–network. Each of the three major structural entities here would have numerous other actors connected to them. They could also be part of other networks independently of the ERP network. They act, through the process of simplification and juxtaposition, as the three most significant nodes of the ERP actor–network.

Structure and Agency in the ERP System of Innovation

The ANT has a particular ability to provide a structured platform to investigate why an innovation works or fails. But the important issue is, is it a tool for problem solving or merely an illustrative device? Either way, it does not really matter. By serving as a template to analyse the implementation of an innovation, it has served its purpose. In the ERP network, we observed that the choice of technology and method of payment are most likely to affect the synchrony of actors. In this sense, ANT as a template is extremely flexible in handling any system or technology involved.

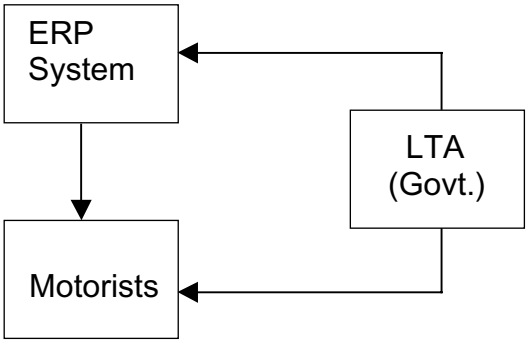

Figure 3. ERP actor–network

Nevertheless, there are two major weaknesses of ANT illustrated in the analysis of the ERP innovation's implementation. First, ANT pays scant attention to larger social implications and externalities of the innovation. In the enrolment process, spill-over effects of the ERP innovation, whether intended or not, arise. They are not adequately dealt with by ANT because ANT fails to recognise these actors as they are not directly related to the network. Similarly, it is not the intended purpose of the ANT framework to take all pertinent social issues into consideration except when they are involved as part of the juxtaposition process. Most of the externalities are treated as social issues not directly related or considered unintended effects of ANT. We have identified seven such externalities.

1. ANT fails to take into consideration the 'quality of life' as a result of the ERP innovation. The 'quality of life' in urban areas depends on the ability of people to do what they desire. This often involves moving from one location to another to partake in various activities. An efficient transport system is a vital asset for fuelling social and culture life. To damage or restrain it may threaten the continuity of the social system and severely harm the very notion of citizenship and the sense of belonging to a community. Hence we see that the automobile, and the supporting transport system, provides the flexibility needed to meet this desire for freedom, while the 'level of service' provided to the traffic system is integral to economic performance and individual satisfaction. The key word is accessibility in its wider sense, ensuring that people have the opportunity to access spaces and services under safe, convenient, and comfortable conditions.[28]

In Singapore, the rationale for road regulation is not focused on the 'quality of life', though it is one of the objectives. But the focus is, largely, on economic factors. According to the LTA, its 'mission is to provide Singaporeans with a World Class transport system … it is important that we succeed because a high standard of transport enhances the quality of life, is good for economic growth and helps us maintain our competitive edge'.[29] Hence transport policies in Singapore have to be viewed on its wider economic perspectives and implications. Transport has a cost, which must be met. Accessibility to the road network has become a scarce resource. At the same time, congestion, pollution, energy consumption, and noise intrusion are important issues in all countries. These negative externalities create social costs. These costs can be met indirectly through taxes and charges on vehicles, fuels or the community. It can also be met directly through charging for the use of the transport system. This direct charging approach must view the provision of transport as a 'service' which can be charged for and is not to be treated as a public good. Direct charging has gained acceptance amongst many transport professionals, however, the general public still perceives the provision of road services as a right and direct charging as reducing the 'level of service' of the road system.[30]

2. As ANT is focused on its contextual system within which it operates, other actors that may be indirectly related are not taken into account. One of the positive spill-over effects of the ERP innovation is its diffusion. Over the past six years, we have observed the diffusion of the technologies involved in the ERP system. There was an increased level of acceptance of the cash card which the government wishes to promote as part of its vision of a so-called cashless society. Many car parks, public libraries and retail shops began to adopt the use of the cash card, some even replacing manual cash collection completely. Even car parks with automated systems are abandoning their traditional car parking tickets with the cash card. Motorists need only insert their cash card into readers located at the entry and exit points of the

car park. This saves motorists the need to queue at payment machines or counters prior to leaving the car park.

In recent years, the diffusion has taken a step further with the emergence of an ERP style system in the car parks. Instead of winding down their car windows to insert their cash cards at entry and exit points, motorists need only insert the cash card into the IU as they would in the ERP system. The overhead sensors installed at the entry and exit points of the car park mimic the ERP gantries and automatically detect and deduct the appropriate parking fee from the cash card via the IU. This helps to reduce the time taken to enter and leave the car park. Not only does this make the driving experience in the car park more pleasurable for motorists, it is also a boon for heavily used car parks. Such an ERP style parking system most definitely places Singapore car parks at the forefront of innovations in merging IT with transportation systems.

3. The ability of the ERP gantries to track the movement of individual vehicles also means a loss of privacy for motorists who may be concerned that their personal space and privacy is further reduced. At the same time, this increases the surveillance capabilities of the government and gives greater control over the public.

4. The use of cash cards as the mode of payment in the ERP system has resulted in several motorists leaving their cash cards almost permanently inserted in the IU. This has led to a rise in car vandalism as the unattended cash cards entice the not-so-savvy burglars to smash the windscreen of vehicles just to make a large enough opening to steal the cash cards left in the IUs.[31]

5. The need to constantly top-up the balance of the cash card has led to much inconvenience to motorists. Motorists who are very busy tend to forget to top up their cash card and end up paying a fine when they have insufficient balance when passing through the ERP zones. The same problem arises when motorists who have low balances in their cash cards enter the ERP system without topping up as they have no idea of the prevailing ERP charges. Motorists are also reluctant to keep large amounts on their cash card as they have no recourse should it be stolen or lost and the balance in the cash card is not interest bearing. This points to a limitation of the ERP system and presents an irreconcilable misalignment of interests as the existing system does not readily have a solution to this problem.

One possible solution is to integrate or link the cash card with personal ATM cards and protect its use through a pin number or biometrics.[32] IUs can be upgraded to support pin number entry or biometric recognition such as thumb prints. This removes the need to constantly top up the cash card as ERP charges are directly deducted from the motorist's bank account. Motorists also need not worry about the theft of their cash cards as they would be useless without pin or biometric verification.

6. Certain models of cars are not approved for use in Singapore as a result of their glare-reducing windscreens which affect the radio communication between the IU and ERP gantries. To solve this problem, IUs have to be repositioned or the windscreens would have to be modified to leave a small area just above the IU without the glare-reducing material. Approval from the LTA is required to reposition the IUs or to import such windscreens. This invariably inconveniences motorists and car importers and limits the choices of the former when purchasing a car.

7. Under the ERP scheme, payment is made for each entry into the restricted zone. Under the old manual system, the area licence gave unlimited entries and re-entries. As a result, most motorists would end up paying more with ERP. The answer by the authorities was that the ERP results the maxim of paying for the

actual use of the road. They also claim that the majority of motorists under the old manual pricing system use the area licence only once a day, with an average of 1.4 trips per licence. Taxi drivers are most likely to be affected as they make an average of four trips per licence. Now under the ERP, charges would have to be borne by the passengers and taxi drivers are less likely to enter the restricted zone without any passengers. This has resulted in fewer taxis available for hire in the restricted zone despite the large number of taxis in Singapore. Re-entry payment has also increased business costs for delivery companies and business owners in the downtown area.

An important weakness of ANT is the treatment of differential power between actors in the network.[33] While the ANT explains the structure of the network and the relations of the elements, its inadequacy shows when it comes to the disparity in power among the actors. Although ANT suggests that each element or actor in the network affects every other element, it does not properly account for the way some elements such as the focal actor (LTA) affect other elements in greater ways. And because each actor has its own individual interests and differential power, this may lead to resistance and threaten the breakdown of the network. In transport matters, despite the state's overwhelming power, other actors also play an important role. Not all actors participate in all the discussions, and when they do, they seldom have equal leverage.[34]

We observe a parallel situation with the characteristics of conflict and struggle of large concerns (such as big corporations, public agencies) that orient scientific research as well as define and control the application of technology vis-à-vis consumers.[35] While meeting most of the demands of the general public, technocrats (comprising government bureaucrats and engineers) make almost all of the decisions without the consultation of the public. They tend to pay lip service to user or consumer feedback, as they often are slow to make changes and even would only change certain elements within a pre-conceived boundary. This means that they already have fixed mindsets, only willing to change non-essential elements instead of engaging the public prior to the implementation. In this way, the actor–network is bound to harbour some misalignment. Depending on the nature and extent of these potential conflicts, they may threaten the successful implementation of the innovation.

Given the impact of ERP on the actors in the network, resistance is bound to arise when they are not given adequate power and made a stakeholder in the policy-making process leading to the development and diffusion of the innovation or at least a chance to have their concerns addressed. The ERP has been implemented for almost five years and despite this relatively long period of time, there still appear some cracks within the system. While the LTA and relevant authorities would like to hail the ERP system as a complete success, there is still a lot of unhappiness and problems, which have not been addressed and remain unsolved.

Any resistance towards the ERP would almost certainly have resulted in violation or the flouting of the law since ERP is legally enforced and compulsory for all users of the road. Though the common violations of the ERP system, such as failing to insert the cash card properly or insufficient cash card balance, may be the result of carelessness, it shows the degree of reluctance or lack of eagerness among motorists in co-operating with the system. However, such resistance was statistically insignificant. According to statistics provided by the LTA,[36] there were about 5.0 violations per 1,000 transactions in October 2002, out of which, the number of 'no cash card' violations was 22,817 (73%) and the number of 'insufficient balance in

cash card' violations was 8,528 (27%). This contrasts with the figures in September 1998 where there was an average of 3.8 violations per 1,000 transactions, of which, the number of 'no cash card' violations was 20,511 (93%) and the number of 'insufficient balance in cash card' violations was 1,462 (7%).

A more visible resistance towards the ERP is seen when motorists deliberately park their vehicles (often illegally) just outside the ERP gantries minutes before the charging period ends or enter the exit of the restricted zone against the flow of traffic. Cases of vehicles caught parking in front of the ERP gantries to stall for time are sporadic and the number is small—about 5–10 per day. Other forms of expressed resistance can be seen from the letters to the editor's forum in the dominant local newspaper, *The Straits Times*. Motorists use this column to express their displeasure with the ERP system (this is the only legal means of 'protest' in Singapore). In the tightly controlled political space of Singapore, these protest letters are to be seen as technological mediation shaping society. However, perhaps the most significant resistance to the ERP system is when motorists do not switch routes to avoid heavily congested roads despite the hefty ERP charges—which render the ERP system ineffective.

Conclusion

The ERP system in Singapore has been operating relatively smoothly and successfully since its implementation in 1998. In October 2002, system availability for ERP gantries was almost perfect at 99.9%. From our analysis as outlined in this paper, we propose that the following factors have contributed to the successful implementation.

1. The process of enrolment was relatively thorough, although some actors in the network took several years to enrol fully. The changeover from the manual system was also carefully planned and efficiently executed.
2. The quick adoption of the ERP was made possible due to the imbalance of power between the heterogeneous elements within the network. The firm leadership from a strong and determined focal actor, the Land Transport Authority, was instrumental. During a study trip to Japan, we found that the Electronic Toll Card (ETC) in Japan (which is not mandatory) was not popular among Japanese motorists. Most of them preferred to pay cash instead. Differential power may directly affect the take up and implementation of an innovation.
3. Like most innovations, success usually follows when the actual benefits of the innovation outweigh the switching costs. For the ERP, this new automated system is more convenient than the manual system it replaced. Hence resistance to the innovation appears to be minimal.
4. There were many controllable and predictable factors in the ERP innovation. The network mainly involves the interaction of machines: the ERP gantries and the IUs. The role of human actors is mainly to facilitate the process by topping up the cash card and remembering to insert it properly. As humans are more complex and harder to predict or control, their minimal involvement is likely to translate into fewer problems. This contrasts with the people-intensive EZ-Link system.[37]
5. The social context in Singapore may have favoured the innovation. In Singapore society, a car is usually considered a luxury item and a status symbol. The city state has one of the best public transportation systems in the world.

> Singapore also has an extensive array of taxi services at affordable rates. As such, many motorists who go for private cars do so not out of necessity but for comfort and prestige and are also able to afford the ERP charges. They are also less likely to resist the system on purely monetary factors.

Nevertheless, we reserve judgement as to whether the ERP has met its original objective of regulating road use as the system, despite having been around for five years, is still evolving.

As with the original social objectives behind the introduction of an electric car spearheaded by the engineers of Electricite de France (EDF) in the early 1970s,[38] the introduction of the ERP in 1998 is intended to herald a possible change in the social morphology of Singapore. It is likely that not many Singaporeans see it in that light. The ERP, if successful, would transform the way commuters perceive the use of public roads.[39] Once free for all who possess the necessary licences, insurance and a vehicle, roads in Singapore will be transformed into a pay-per-use facility. This differs from the traditional toll booths in other countries where their sole purpose is to recover the cost of infrastructure investment.[40]

Already in the pipelines are plans to introduce ERP gantries to more roads, widen the restricted zone and even erect restricted zones within existing restricted areas. There is even a plan to eventually replace the entire ERP with a global positioning system (GPS) to track and charge road usage through satellite monitors. Such moves have serious social and economic consequences because they affect the medium that facilitates the execution of citizens' daily social and economic activities, and their 'quality of life'. This is not to mention the serious infringement on privacy, civil rights and personal autonomy of motorists. GPS-based navigational aid and security devices have already been in use in many countries.[41] These devices, while providing great safety and security for drivers, pose the danger of putting 'Big Brother in the driver's seat'.[42]

People in Singapore may decide, for example, to relocate their homes or workplace to avoid hefty ERP charges or those economically not well off people who own cars out of necessity may be forced to give up driving completely, which appears to be the objective of the authorities. This kind of social engineering mediated by technological innovation can then cut both ways; while technological devices like automobiles used to give the freedom to move anywhere as one wished, a conscious decision not to own it may reinstate that freedom for an entirely different reason. Finally, the ERP innovation system should not be seen in isolation as a successful (so far) innovation without juxtaposing it with other technological ventures[43] within the larger social milieu of Singapore, where the instrumental rationality of finding technological solutions to complex socio-economic problems has been the core of its political culture of nation building. Since the political power embedded in the ERP system is biased heavily in favour of the government, many Singaporeans may see it as yet another attempt on the part of the state to manage their lives.

Notes and References

1. A. Lee, 'London to expand its road pricing area', *The Straights Times*, Singapore, 13 August 2004, p. 14.
2. A. P. G. Menon, 'ERP in Singapore—a perspective one year on', *TEC*, February 2000, pp. 40–5. London's system is only partially automatic compared to Singapore's fully automated

electronic road pricing system. In the case of London, camera's mounted at the entrance of the city centre roads read the license plate numbers of vehicles and the optical reader sends the message to a centralised computer system, which then sends the toll charge to the motorists by post.

3. Actor–network theory or ANT broadly follows the sociology of scientific knowledge (SSK) tradition to explain the social shaping of technological artefacts and systems in that the 'construction' of technology is a social process involving a heterogeneous array of actors (both humans and non-humans). Prominent theoreticians of ANT are B. Latour, *Science in Action: How to Follow Scientists and Engineers Through Society*, Harvard University Press, Cambridge, MA, 1987; B. Latour, 'The Prince for machines as well as for machinations', in B. Elliot (ed.), *Technology and Social Processes*, Edinburgh University Press, Edinburgh, 1988, pp. 20–43; and M. Callon, 'Society in the making: the study of technology as a tool for sociological analysis', in W. E. Bijker, T. P. Hughes and T. Pinch (eds), *The Social Construction of Technological Systems*, MIT Press, Cambridge, 1989, pp. 83–103; M. Callon, 'Actor–network theory—the market test', in J. Law and J. Hassard (eds), *Actor Network Theory and After*, Blackwell, Oxford, 1999. Although Latour later distanced himself from ANT, we will follow Callon's interpretation of ANT in this article.
4. T. P. Hughes, 'The seamless web: technology, science, etcetera etcetera', *Social Studies of Science*, 16, 1986, pp. 281–92, follows the same constructivist framework to explain technological change.
5. This is especially the case because of its rather untenable claim of symmetry in such matters as power among all actors of the network.
6. For more on Singapore's ruling ideology based on communitarianism, see B. H. Chua, *Communitarian Ideology and Democracy in Singapore*, Routledge, London, 1995.
7. Callon, 1989, *op. cit.*
8. D. F. Noble, 'Social choice in machine design: the case of automatically controlled machine tools', in Donald MacKenzie and Judy Wajcman (eds), *The Social Shaping of Technology*, Open University Press, Milton Keynes, 1985, pp. 109–24.
9. T. J. Pinch and W. E. Bijker, 'The social construction of facts and artifacts: or how the sociology of science and the sociology of technology might benefit each other', in Bijker *et al.* (eds), *op. cit.*, pp. 17–50.
10. L. Winner, 'Do artefacts have politics?', in MacKenzie and Wajcman (eds), *op. cit.*, pp. 2–25, argues that the power embedded in technological structures could act like legislative tools (laws) because once these structures are erected everyone has to abide by the particular directions to use it or accept its existence as part of their social and physical space. Violations could lead to legal sanctions or physical harm. In rare instances, it so happens that these structures or artefacts are designed by individuals who get around legislative scrutiny and legitimacy by imposing their political ideology (often their prejudices and capricious political beliefs) on society my misusing their professional positions within their organisational settings. Winner shows how a bigoted engineer reinforced racial segregation by designing overpasses on Long Island expressways so low so that buses (which were the only means available for poor blacks) could not reach rich upscale white areas where he lived.
11. More than a paradigm shift, this new economic mode is actually a rupture of industrialism and the rise of information capitalism. For more on this argument see, G. Parayil, 'Digital divide and increasing returns: contradictions of informational capitalism', *The Information Society*, 21, 1, 2005, pp. 41–51.
12. J. Law, 'Technology and heterogeneous engineering: the case of Portuguese expansion', in Bijker *et al.* (eds), *op. cit.*, pp. 111–34.
13. *The World Factbook* by the CIA at ⟨http://www.cia.gov/cia/publications/factbook/geos/sn.html⟩, accessed on 26 November 2003.
14. Roads and expressways are considered public goods, which means they are non-excludable and non-rival. However, unlike other public goods like air, oceans and national defence, roads and highways in these days of neo-liberal economic climate (of deregulation and privatisation) could be excludable and rival good (could be owned or operated privately). But in

most countries (as in Singapore) roads are publicly owned. If left unregulated, roads like other public spaces could lead to over-use and congestion (a variant of the tragedy of the commons situation).

15. E. A. Vasconcellos, *Urban Transport, Environment and Equity: The Case for Developing Countries*, Earthscan, London, 2001.
16. T. D. Hau, 'Economic fundamentals of road pricing: a diagrammatic approach', Working Paper No. WPS 1070, Transport Division, Infrastructure and Urban Development Department, The World Bank, Washington, DC, 1992. According to Hau, supply-side actions could be restricted by physical space and fiscal constraints.
17. LTA (Land Transport Authority), *White Paper on a World Class Land Transport System*, Singapore Land Transport Authority, Singapore, 1996.
18. Details of the four systems considered by the LTA are found in A. P. G. Menon and K. K. Chin, 'The masking of Singapore's electronic road pricing system', paper presented at the International Conference on Transportation into the Next Millennium, Centre for Transportation Studies, Nanyang Technological University, 9–11 September 1998.
19. This is very similar to the ERP system being used in London.
20. The IUs are colour-coded for different types of vehicles because toll charges vary for different types of vehicles. This is also supposed to stop switching of IUs. See Menon and Chin, *op. cit.*
21. Thomas Hughes is one the foremost theorists of the large technological systems theory to explain the development and diffusion of such technological systems as electric power systems. See T. P. Hughes, *Networks of Power: Electrification in Western Society, 1880–1930*, Johns Hopkins University Press, Baltimore, 1983; and T. P. Hughes, *Human-built World: How to Think About Technology and Culture*, University of Chicago Press, Chicago, 2004.
22. According to Everett Rogers, *Diffusion of Innovations*, 4th edn, The Free Press, New York, 1995, the founder of DoIT, diffusion of innovation is 'the process by which an innovation is communicated through certain channels over time among the members of a social system' (p. 35). While similar to ANT in that it examines how technology is accepted or rejected by groups in society, the focus of DoIT is to answer two critical questions. How do ideas spread among a group of people over time? How can we speed up this process? In doing so, the DoIT model would require the innovation be introduced on a voluntary nature. To give a simple example, it would be rather pointless to measure the rate of diffusion of the traffic light system as an innovation as road users often have little choice but to comply or risk breaking the law. The ERP innovation system is not as extreme a case as the traffic light, as there is a semblance of choice and resistance is available to road users as we show in this paper. DoIT emphasises the communication of innovation as it is diffused rather than its development and implementation. It is inherently concerned with the human actors in the system and does not accord the same attention as ANT would on non-human actors, if at all. A key factor of DoIT is the rate at which an innovation is adopted over time. This makes it less suitable to assess the changeover process of an innovation where time is a constant rather than a variable.
23. See Latour, 1988, *op. cit.* ; Callon, 1989, *op. cit.*
24. See Callon, 1999, *op. cit.*; Law, *op. cit.*; Law and Hassard, *op. cit.*
25. Callon, 1989, 1999, *op. cit.*
26. Law, *op. cit.*
27. Menon and Chin, *op. cit.*
28. Vasconcellos, *op. cit.*
29. LTA, *op. cit.*
30. W. Young and P. Daly, '"Quality of life", road pricing and the "level of service" of urban roads', paper presented at the International Conference on Transportation into the Next Millennium, Centre for Transportation Studies, Nanyang Technological University, 9–11 September 1998.
31. This is unlike in other countries where car burglars break into the cars for stealing stereos or car parts. Cash cards can be used at vending machines and stores to make purchases without the need to key-in personal identification numbers (PIN). See the report, 'CashCard left in car? That's like waving cash at thieves', *The Straits Times*, Singapore, 13 August 2004, p. H2.

32. Biometric technologies received a tremendous boost recently after the word-wide concerns of security following the September 11 terrorist attacks in the United States. Singapore is actively trying to get on the biometrics bandwagon and hence the possibility of such an integrated biometric-smartcard system (bundling of national identity card, cash card, ATM card and so on) could become part of this technological trajectory.
33. This is because ANT adheres to the symmetry principle of the 'Strong Programme' in the sociology of knowledge. See D. Bloor, *Knowledge and Social Imagery*, Routledge and Keegan Paul, London, 1976, such that the same type of analysis should be attributed to all components, human as well as non-humans, and also to failed as well as successful innovations.
34. Vasconcellos, *op. cit.*
35. Callon, 1989, *op. cit.*
36. The months of October 2002 and September 1998 were chosen for comparative purpose. As ERP rates are reduced during school vacations, such months are avoided. The charging period in 2002 is lower than 1998 as ERP hours were reduced.
37. Introduced by the LTA in 2002, the EZ-Link is a magnetic card that requires commuters to tap card readers when boarding and alighting public buses. However, a flurry of complaints, resistance and inefficiencies arose. Many commuters forgot to tap their cards when alighting and as a result were charged the maximum fares; those who wished to alight from the entrance of the bus had difficulty doing so. LTA probably felt that the EZ-Link system was a fantastic innovation as it purports to save time in boarding buses and trains since the magnetic cards do not have to be inserted into card readers as was done previously.
38. Callon, 1989, *op. cit.*
39. Although not a stated objective of the LTA, it is also an important milestone in Singapore's drive towards a cashless society.
40. However, many cities are contemplating Singapore-style ERP systems to stem road congestion in and around city centres. For example, London has introduced an ERP system earlier this year, but it is a passive system of billing car owners who are tracked by an elaborate video and computer linked system. Lisbon is introducing a congestion tax on drivers who want to enter the business and entertainment districts in the city centre from 2004. This is a passive non-electronic system where drivers have to display the congestion tax stamp on the windscreen. See, 'Lisbon to tax car drivers in city centre', *The Straits Times*, 13 December 2003, p. 24.
41. One such device is the 'OnStar' personal security system installed in millions of cars in the United States. For details see J. Schwartz, 'Technology may put Big Brother in driver's seat', *International Herald Tribune*, Tuesday 30 December 2003, ⟨http://www.iht.com⟩, accessed on 30 December 2003. OnStar is a company owned by General Motors. The communications and tracking feature available with this device is used by more than two million drivers in the United States. The system helps the drivers to get help on directions and to unlock cars in case of being locked out. But the most sought after feature is to thwart car thefts as the system helps the police to intercept the thieves. Despite the great boon that drivers get by installing the system, it also invites Big Brother into the car with all its consequences.
42. Schwartz, *op. cit.*
43. These include the development of a thriving electronics and semiconductor manufacturing hub, the development of an 'Intelligent Island' of fully networked communications system, and the present all out push to make the city state as a 'Biopolis' of Asia by the development of a thriving biomedical and bio-informatics hub, among others. See G. Parayil, 'From Silicon Island to Biopolis of Asia: innovation policy and competitive strategy in Singapore', *California Management Review,* 47, 2, 2005, pp. 50–73, for details of Singapore's innovation systems and the ensuing dynamics of technological development.