SUSTAINABLE URBAN TRANSPORT: SMART TECHNOLOGY INITIATIVES IN SINGAPORE

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ABSTRACT
Achieving sustainability is one of the major goals of many urban transportation systems. Over the years, many innovative policies have been attempted to achieve an efficient, safe, and sustainable transport system. Those policies often require smart technologies to assist implementation process and enhance effectiveness. This paper discusses how sustainability can be promoted by embedding smart technologies in a modern transportation system. In particular, this paper studies the transport system of Singapore to address how this system is addressing sustainability through the use of smart technologies. Various technological initiatives in managing traffic flow, monitoring and enforcement, sharing real-time information, and managing revenues are discussed in light of their potentiality in addressing sustainability issues. The Singapore experience provides a useful reference for the cities intending to develop and promote a sustainable transport system.

Keywords: Smart transportion, Sustainable transportion, Smart technology, Singapore.

INTRODUCTION

Achieving sustainability has become one of the fundamental goals of many urban transportation systems in the past two decades. The emerging concept of sustainability (*1*) has developed enormous interests among researchers and practitioners to develop a sustainable transport system. While many have focused on developing an appropriate definition of a sustainable transport (e.g., *2–5*) and measures and indicators of sustainability (e.g., *6–10*) so as to assess if a transport system is moving towards or away from sustainability, many have put forward different strategies to make a transport system sustainable (e.g., *3, 11*). Defining sustainable transport and identifying indicators are important to make this concept more correct, focused and measureable. However, identifying and developing strategies towards sustainability is the key to move forward since those are real steps in shaping a sustainable transport system.

A wide range of strategies has been proposed by many researchers and being implemented in many cities in recent years. Some of the major strategies include integrating transport and land use, managing motorization, promoting public transport as an alternative to private transport, pricing and financing, and adopting and promoting environment-friendly technologies. These strategies in general follow the three basic policy sets of a transport system development – supply measures, demand management and environment-friendly initiatives, in order to seek for a proper balance between the transportation and resource needs of the current and future generations, which is the prime objective of the sustainable transport development (*2, 12*).

While transport authorities require policies to promote and ensure sustainability, the policies often require technologies for implementation and effectiveness. Technologies are expected to reduce greenhouse gas emissions and increase efficiency of transport operations, whilst the policies are to reduce traffic volume and resource usage. Figure 1 illustrates how smart technologies in conjunction with transport policies can be embedded in a transport system to achieve sustainability. Transport authorities and agencies develop policies and utilize smart or intelligent technologies to implement and make the policies effective, together focusing on the development of a sustainable transport system. Development of the policies is also influenced by advancements in technologies, and vice versa. Nijkamp (*13*) illustrated how the policies and technology changes influence each other in development of sustainable transport by changing mobility patterns. Recent advancements in smart transport technologies allow transport authorities to develop and implement policies easily and efficiently through using those technologies. Therefore, development of policies and technologies are two interdependent tasks for achieving sustainability in transport.

Studying the practices of sustainable policies and associated smart technologies in different cities is important for the cities with relatively unsustainable transport system to learn from those with a more sustainable one. Since implementation of policies and technologies varies greatly on regional characteristics, such as economic development, political systems and cultural developments, it may be more appropriate for a city to learn from the other cities in its same region/continent. The transport system of Singapore could be a useful example for others, particularly for the Asian cities, to see how different initiatives on policy and technological implementation are working together to achieve sustainability. In the past, Singapore experiences helped other Asian cities to solve their transportation problems. For example, Shanghai followed the Vehicle quota system of Singapore for controlling motorization when it introduced auctioning private car licenses (*14*). To better allow other cities to learn from Singapore, it is necessary to explore the initiatives taken to promote sustainability in the transport system of Singapore. It would be interesting to see how sustainability is fostered in transport management under the pressure of economic development and the severe land and resource constraints in Singapore. Han (*14*) have discussed the policies being practiced in Singapore to manage motorization and sustainability. However, it is equally important to study the initiatives taken using smart technologies to move towards sustainability.

This paper explores the smart technology initiatives in the transportation system of Singapore for promoting and ensuring sustainability. In particular, it examines how the technologies address different issues of sustainability, such as protecting environment, fostering economy, ensuring safety and social equity, enhancing mobility and accessibility, and improving system efficiency. By focusing on smart features of technologies and their implementation histories, the potentials of those technologies are explored from the sustainability viewpoint. In the rest of the paper, starting with a brief introduction on smartness and sustainability of a transport system, the land transport experience of Singapore on addressing sustainability through the use smart technologies is discussed.

SUSTAINABLE AND SMART TRANSPORT SYSTEM

A sustainable and smart transport system is one that addresses the issues of sustainable development by introducing smartness into the technologies used to operate and manage a transport system. It is, therefore, necessary to understand what constitutes sustainability and smartness in a transport system.

Sustainable Transport

Following the idea of sustainable development (*1*), many researchers have attempted to develop a definition of sustainable transport and refine it. Black (*2*) defined it as "satisfying current transport and mobility needs without compromising the ability of future generations to meet these needs". Although this definition views sustainable transport as an expression of the concept of sustainable development in transport sector, advancing sustainability in this sector tend to be particularly difficult because of its complex nature that involves social, technical and economic components (*11*). Probably because of this difficulty, there is still no single universally accepted definition of transport sustainability.

Given this lack of a universally accepted definition, a popular approach of addressing it is to look at the objectives and desirable attributes of a sustainable transport system. A study on sustainability initiatives in North America, Europe and Ocenia (*15*) has also identified this lacking and reported that most of the initiatives share common objectives, such as ensuring mobility, accessibility and safety within environmental limits. May et al. (*16*) have proposed five desirable attributes of a sustainable transport system such as (1) liveable streets and neighbourhoods, (2) protection of the environment, (3) equity and social inclusion, (4) health and safety, and (5) support a vibrant and efficient economy. Through a review of literatures, Castillo and Pitfield (*10*) have further shown that those attributes of a sustainable transport commonly suggested and practices generally fit well into these attributes.

In development of the desirable attributes of a sustainable transport system, some have keep focus on the three basic issues of sustainable development – environmental protection, social welfare, and economic development. The definition of sustainable transport by the European Council of Ministers of Transport (*17*) is a popular one (see *5, 11, 18*) that includes most of the environmental, social and economic concerns. The Centre for Sustainable Transport (*19*) has also identified several attributes with respect to environment, society and economy as a vision towards sustainable transportation by 2035. In light of these attributes, a sustainable transport system can be defined as one that firstly, allows for the safe and environmentally harmless basic means of access and development on the individual, business and societal level, while promoting equity within and between generations; secondly, is reasonably priced and runs efficiently, providing choice of transport mode as well as support for a competitive economy and good regional development; thirdly, keeps production of emissions and waste within the carrying capacity of the natural environment and minimizes consumption of renewable resources and non-renewable resources (at or below the rates of generation and at or below the rates of development of renewable substitutes, respectively), while minimizing the impact on the use of land as well as production of noise.

Smart Transport

Recent advancements in technological developments have made urban transportation systems more efficient through use of smart technologies. A smart technology is a self-operative and corrective system that requires little or no human interventions. Typically, it has three elements – sensors, command and control unit, and actuators, in order to possess three basic capabilities - sensing, processing and decision making, and acting (*20*). To have sensing ability, a smart technology has the ability to extract information from its sensors and communicate with its command and control unit or with external devices. Typically, the sensors embedded in a device automatically collect information regarding the state of the device which are transmitted to command and control unit for processing. The command and control unit is able to process and interpret the information received from sensors and further take decisions on what to do next and transmits the decisions to the actuators. Upon receiving instructions, the actuators execute the decisions into actions. The sensors again collect information after the action taking process and transmits those to command and control unit, thus a smart technology forms a closed-loop monitoring and action taking process.

While many technologies in transportation sector possess the three basic capabilities, now-a-days smarter technologies are being developed to enhance the quality of the capabilities. A smarter technology possesses capabilities of accurate sensing, fast processing and reliable control (i.e., decision making and acting). In addition to these enhanced basic capabilities, technologies are also being advanced to possess higher-order capabilities, such as adaptability, self-optimization, interoperability, and predictability. Smart technologies should be aware of situations occurred frequently and possess adaptability to adjust its performance at those situations, thus becoming able to learn from operations. Technologies also need to have abilities for self-optimization (i.e., able to optimize its performance for best outcomes) and interoperability (i.e., be able to connect to a network of devices) for achieving an optimized performance for a network. Sharing of information between devices of a network is an important aspect of networked operation. Predictability is another higher-order ability a smart technology possesses. It has the ability of detecting faults and be able to recover those by itself.

The basic, enhanced and higher-order abilities of a smart technology provide a general outline of the desirable abilities of any smart technologies in transport system. However, clearly there is a room for discussion on whether all technologies should possess all of these smart abilities. Generally different technologies serve different purposes depending on their spatial coverage. For example, a smart traffic signal system is required to optimize traffic flow at a network level by adjusting signal timings of all intersections in that network, whereas a red light enforcement camera is only responsible for detecting red light runners at a particular intersection. While the former requires all of the enhanced capabilities and some higher-order abilities, such as self-optimization (optimizing traffic flow at different approaches of an intersection) and interoperability (optimizing for adjacent intersections), the later only requires the enhanced capabilities. Because of the diversity in the purposes of using technologies, all technologies may not posses all of the abilities outlined under the higher-order category.

Having grasped the desirable attributes of sustainability and smartness, a sustainable and smart transport system can be viewed as one that ensures environmental, social equity and economic sustainability by utilizing smart technologies.

SMART TECHNOLOGY INITIATIVES IN SINGAPORE

Singapore is a tiny island nation with land area of 710.2 square km and 4.8 million inhabitants, as in 2008 (*21*). With the land constraint, it has road capacity of 8774 lane-km with 1058 lane-km of expressways and 2923 lane-km of major arterials, totally accounting for 12% of the total land area. It has a controlled growth of motor vehicles (see Han, 2010 for details of the associated policies) resulting into a total of about 0.9 million vehicles with 53% of private cars, 16% of motorcycles, and 1.7% (15,327) of buses. With the controlled growth of motorized traffic, Singapore has been able to maintain average peak hour speeds of 63.3 km/hour and 26.7 km/hour at expressways and arterials respectively. As a part of a people-centred public transport system, it is maintaining a world class public transport network, which covers 118.9 km of mass rapid transit, 28.8 km of light rapid transit, and 3268 bus fleets operating in 344 bus routes. The Land Transport Authority (LTA) of Singapore has been putting enormous efforts to promote public transport and make it a choice mode to travellers for advancing towards sustainability. It has targeted to increase the public transport mode share during the morning peak hours from 63% in 2008 to 70% by 2020 (*22*). Singapore has also maintained a world-class taxi system as a high end service with 5022 taxis per million populations in operation.

Because of the land constraint, Singapore has mainly focused on innovations in policies and supporting technologies for meeting the mobility needs of people. With the introduction of smart technologies, it has been developing its transportation system to be more efficient and sustainable. Usage of the technologies in the transport system of Singapore can be broadly categorized into four divisions, according to their primary functions, such as Control systems, Monitoring and enforcement systems, Information management systems, and Revenue management systems. In classifying the smart technologies, only those available at city-level (i.e., requires an infrastructure system to become operational) are considered. The user-level technologies which do not require an infrastructure, such as the smart vehicle control systems, collision avoidance systems, and the driver safety monitoring systems are left out. This is because use of these technologies not necessarily reflects the sustainability initiatives of a city's transport system; rather it depends on the maker of the vehicles. Technological initiatives on environment friendly cars are also left out as those do not fit into the scope of this paper.

Table 1 provides a comprehensive summary of the smart technologies used in Singapore's transport system and the potential ways of addressing sustainability in transport. The control systems manage traffic flow and safety at traffic intersections by utilizing physical infrastructures, such as traffic signals. The monitoring and enforcement systems ensure that motorists are obeying traffic rules through a set of surveillance systems. The information management systems collect, process and share traffic and travel information to travellers via different fixed and mobile platforms. The revenue management systems process transactions related to public transport fare and toll payments. The smart technology usage and associated sustainability benefits are discussed in the subsequent sections.

Control Systems

To ensure system efficiency and safety at traffic intersections, Singapore has been taking initiatives on automation of traffic control systems. These include an adaptive traffic signal system (GLIDE) for all of the intersections in Singapore which continuously collects traffic information and adjust signal timing accordingly. Automatic detection of vehicles (by using wire sensors) and pedestrians (by using push button) at each approach allows each intersection to allocate green time based on real-time demand. Moreover, by coordinating traffic signals at adjacent intersections the system is able to optimize travel time by minimizing the number of stops at intersections. This optimization essentially makes traffic flow smoother and more efficient at the intersections as well as at the network level. Also, because of less number of stops and less waiting time at intersection, fuel consumption and emission production reduces.

In order to improve public transport services, the LTA has introduced a transit signal priority scheme (B signal) for providing priority to buses at signalized intersections. This signal system detects buses approaching some major intersections and correspondingly extends the green time for them to clear the intersection. The B signal also turns green ahead of the green lights for other vehicles to allow buses a head start and opportunity for changing lanes. Introduction of the B signal has resulted in a shorter bus journey time and enhanced reliability of buses as a viable alternative to private transport. While Singapore is utilizing the transit signal priority system for betterment of its bus services, many of the major cities in Asia like Hong Kong, Shanghai are yet to implement it.

To enhance pedestrian safety at intersection, several technological initiatives have been taken in recent time. Elderly pedestrians, who may require more time to cross the road, are allocated additional green time through a detection system, which requires the elderly to tap their senior citizen concession card on card readers mounted on the traffic lights poles. Providing facilities for elderly pedestrians were a concomitant necessity as Singapore has been facing challenges of a fast aging population. For instance the old-age support ratio (number aged 15-64 years per elderly aged 65 years and above) has been dropped from 17 in 1970 to 8.2 in 2010. Green time countdown timers and audio signals have also been installed in many pedestrian crossings to allow physically challenged pedestrians to cross safely. Intelligent road studs are being installed at 17 major intersections (*23*) which alert motorists of the pedestrians crossing the road by blinking the studs on the pavement when the green man signal is on. The road studs significantly improve safety for pedestrians and motorists at intersections, particularly for the elderly, less mobile and children.

Monitoring and Enforcement Systems

Smart technologies have been widely used in Singapore for monitoring traffic conditions and enforcing rules and regulations. Technological advancements now allow transport authorities to continuously monitor transport facilities through accurately sensing disturbances in traffic flow and identifying violations. A smart surveillance system would produce less violation of rules, less number of incidents, and less clearance time after incidents, thus leading to obtaining smoother and safer traffic flow, which is important for a fostered economy. Examples of using smart technologies in traffic enforcement are discussed in the succeeding paragraphs.

To ensure motorists obeying the posted speed limits on the roads, Singapore has been using automated laser based speed cameras along with the traditional hand-held speed guns. There are 45 possible locations having installed the speed cameras (in July 2010), as listed by Traffic Police (*24*). These cameras automatically detects over-speeding vehicles in real-time and summonses are issued afterwards by traffic police to the offender motorists. Reducing over-speeding cases has a great potential for improving safety at high speed roads. While speed cameras are used to enforce the speed limit, variable speed limits signs are used to guide motorists about a smooth cruising speed. Variable speed limit signs are dynamic signs to display advisory speed limits based on changing traffic flow conditions.

Singapore has been putting efforts on reducing red light runners by installing more red light cameras in order to ensure safety at intersections. Once a motorist crosses the stop line of an intersection when the red light is on, the pole mounted cameras automatically take snapshots of the vehicle registration plate to identify the red light runner. Reducing red light running cases have great potential in improving safety for motorists, particularly for motorcyclists who usually have an early start because of queuing in front of other traffic (*25*).

To further enhance safety at intersections, a monitoring system involving advanced surveillance cameras (J-Eyes) is in operation at major signalized intersections. It helps operators at traffic control centre in monitoring traffic condition at intersections in order to detect irregular traffic situations, such as congestion, illegal parking and loading or unloading. It also helps to detect causes of congestion at or near intersections. There are about 280 cameras (in May 2010) in operation (*23*) for managing traffic flow and enforcement at intersections.

In addition to the intersections, surveillance cameras are also being installed along the expressways in Singapore. The Expressway Monitoring and Advisory System (EMAS) is a smart incident management tool for monitoring and managing traffic along expressways. It uses a detection camera system to automatically detect incidents and congestion in real-time which are verified by using a surveillance camera system. Real-time detection and verification allows for prompt activation of recovery vehicles and other authorities (e.g., Traffic police) to ensure quick restoration to normal traffic flow, thus minimizes congestion and reduces fuel consumption and emission production. The continuous monitoring feature of the EMAS also helps traffic authorities to identify causes of congestion and to enforce traffic offences, such as detection of offending party in an incident. The EMAS service is currently available for the expressways, and will be extended to 10 major arterials by 2013 (*23*).

To promote bus service, several policies have been implemented in the past years, such as Bus lanes, Full day bus lanes, and Mandatory give-way to buses (see *22* for detailed description of the policies). Arising from public feedbacks on the problems in Singapore's public transport system (e.g., long waiting time, erratic bus arrival), the LTA targeted to increase the network of bus lanes to 150 km and full day bus lanes to 23 km by June 2008 from 120 km and 7.6 km (in 2007) respectively (*22*). These policies together targeted to improve travel time of buses (increase average bus speeds to 20 - 25 kph by 2009. To regulate these policies, the LTA utilizes a smart bus lane enforcement system. It includes installing enforcement cameras on-board the buses that travel along the routes with bus lanes. A total of 90 buses of 12 routes were fitted with the cameras (in June 2008) to detect violations of the bus lanes (*23*). With a little human intervention, the enforcement system is able to enhance the bus lane and the full day bus lane policies in order to ensure priority for buses. These initiatives on providing priority to buses on roads would enhance the effectiveness of the bus services and provide an alternative and affordable choice mode to many travellers.

Information Management Systems

Providing real-time traffic information to travellers is important to make a transport system efficient. Singapore has established a smart traffic information sharing platform which enables travellers to receive real-time traffic information on traffic conditions, public transportation services and parking lot availability. The LTA have launched a common platform (MyTransport.SG) for accessing traffic and travel related information (*26*). Different information management systems under this platform, which are broadly categorized into two divisions – traffic news broadcasting and public transport information sharing, are discussed in this section.

Traffic News Broadcasting

Travellers on roads or at home can access information related to traffic conditions, such as congestion, accidents, available parking spaces, and estimated travel times on major roads. These are obtained by combining the information collected from different smart systems, such as the EMAS, GLIDE, J-Eyes, and TrafficScan. The TrafficScan is a smart system which uses travel information (location and speed) of taxis equipped with Global Positioning System (GPS). It provides average travel time along roads to travellers so that they can plan for a smoother journey in advance. Information on accidents and congestion, obtained from the EMAS and J-Eyes systems, are also shared in real-time through a wide range of modes. In addition to the portals of the LTA and other organizations (e.g., SBS and SMRT), traffic information are shared through different in-vehicle devices (e.g., radio, mobile media) and variable message signs (VMS) along roads. Sharing of traffic information allows travellers to plan their routes in advance so as to avoid the roads with congestion or accidents. Also, travel time displays along roads facilitate the route selection and modification process while travelling.

Different dynamic signs are also used to provide real-time information on individual motorists, such as Your Speed Sign (YSS). The YSS displays instantaneous speed of motorists on signboards along roads to alert them about their speed.

To provide more reliable traffic advisory information, the LTA is developing a smart traffic prediction tool which predicts traffic flow and speed using advanced statistical techniques. By utilizing historical and real-time traffic information, this tool currently (under trial phase) can achieve 85% accuracy in predicting traffic volume and speed 10 minutes in advance (*23*). Initiatives on further research and development are being taken to improve the predictability of the tool so that traffic flow can be anticipated and managed by minimizing congestion. Accurate prediction of traffic flow would help transport authorities to divert traffic from the congested roads to those less congested, thus increasing system efficiency.

To promote an efficient use of parking facilities and to reduce the travelling time of searching for a parking lot, Singapore has developed a smart guidance system that disseminate real-time information on available parking spaces . Data on available parking spaces are collected from various car parks in an area and are processed in a central computer in real-time in order to display at roadside electronic information panels positioned at key locations. Currently there are a total of 24 panels displaying parking guidelines in the CBD (*23*). Motorists are able to make an informed decision on which car park to use while driving inside the CBD, thus the parking guidance system reduces the unnecessary travel time for parking space searching and the traffic flow in these areas.

Public Transportation Information Sharing

Real-time dissemination of public transport information is important for travellers to choose the best route (e.g., fastest, cheapest) to their destinations according to their preferences. To develop a people-centric public transportation system, Singapore has developed an advanced passenger information system. Information related to public transport services are made easily accessible to passengers on different platforms, such as internet and mobile phones. Availability of information on public transport services increases accessibility and promotes public transport as a viable alternative mode to travellers. The four important features of the passenger information system include an integrated public transport map, a public transport travel advisor, on-board information services, and an advance taxi booking system.

The integrated map service allows travellers to access information on multi-modal transit alternatives to meet the needs of their door to door journey. Service maps of bus and train services are available at stations, interchanges and on-board. Apart from the maps, travellers can also access information on the arrival times of next buses real-time at many bus stops (76 bus stops were equipped with information display panels at 2008) to better manage their waiting time and make informed travel decisions (*27*). Travellers can also access the information on internet or through mobile phones (via SMS). The LTA planned to cover all bus stops under this service by March 2010 (*22*). As updated on June 2009, this service was provided for 215 bus stops (*28*). For train services, arrival time of next train is available at display panels on platforms and at close proximity of stations.

The public transport travel advisor features a web-based door-to-door multi-modal journey planner, launched in July 2008, which allows travellers to decide on their preferred routes (*27*). Through multi-modal integration, it is able to search for the fastest, cheapest or shortest distance route by combining different travel alternatives. Accessibility of internet on mobile phones has made this travel planning service available to travellers before starting a journey or even while at the journey. This journey planner indeed improves accessibility and appeal of public transport as a preferred mode to many travellers.

To enhance on-board passenger services, passengers are provided real-time information on next stop or the whole route of the transit services. Many buses and trains are equipped with display panels that show the next stop information (in text format or blinking light indicating next stop on the whole route) so that passengers are informed of their alighting stop in advance.

To bridge the gap between private and public transport by providing a high end personalized service, Singapore has been maintaining a world-class taxi service. To offer advanced and instantaneous booking service, different taxi service providers in Singapore are using smart taxi booking systems. Passengers are able to book a taxi through internet (from home) and mobile phone call (on the road) to the contact centres of respective service providers. The contact centres wirelessly connects their taxis by using General Packet Radio Service technology and in-vehicle mobile data terminals to process the booking requests. To make the booking procedure simpler, the LTA has introduced a common telephone number for all services so that passengers do not need to remember different numbers for different service providers (*29*). SMS-based booking service is also available which saves time on waiting for a call to be answered by contact centre and waiting on the line for confirmation of taxi. The SMS-based service is also useful to the speech and hearing-impaired passengers. While the phone-call-based booking is common in many Asian cities (e.g., Tokyo, Hong Kong, Shanghai), only Singapore has a SMS-based booking system that can bypass operators in contact centre and supports English. Singapore's smart taxi booking services together helps to achieve the quality of service expectations – a waiting time of less than 5 minutes to confirm a taxi booking (at least 90% cases) and 10 minutes for a taxi to arrive once a booking is confirmed (at least 85% cases) (*30*).

Apart from the above initiatives taken to disseminate traffic information, the LTA is looking forward to utilize their under-planning second generation ERP (Electronic Road Pricing) system (ERP II) in collection and dissemination of traffic information. It is hoped that successful implementation of the ERP II with GPS-based technology will open up a wide range of opportunities for enhancement of information dissemination (*22*). The ERP II will allow motorists to plan the time, mode and route of their journeys in advance. It also possesses potential for dynamic fleet management of logistics and taxi companies, for improving the operation system of emergency services by giving priority to emergency vehicles when needed, and for relieving congestion by spreading traffic over different modes and routes. These potentialities will help to increase travel time saving and the overall efficiency of road network.

Revenue Management Systems

Managing fast and accurate transactions is important for a transport system to be smarter and more efficient. Singapore has been utilizing smart technologies for better management of revenue systems, such as public transportation fare payment, parking charge payment, and toll collection.

To manage fare payments in the public transport system, an integrated fare structure for different modes has been implemented in Singapore. The LTA has launched new generation electronic payment system – the Symphony for e-Payment (SeP) in December 2008 which allows seamless transfers among different public transport modes. The SeP requires travellers to use the CEPAS card, which is a contactless tap-and-go smart card, for public transport fare payment, electronic road pricing payment, parking charge payment, as well as payments at many retail outlets (e.g., McDonald's restaurants, 7 Eleven). Before the SeP system, travellers were required to use different cards for public transport fare payment (the EZ link card) and the other payment services (cash cards). The SeP features quick and accurate transactions to facilitate a faster boarding and alighting process to buses and trains, thus reducing the overall journey time. Introduction of the distance-based through-fare structure in July 2010 (see *31* for details) has made transfers more seamless and convenient by removing the existing fare penalty associated with each transfers, thus making the public transport system more integrated and affordable.

Singapore has been using the Electronic Road Pricing (ERP) since 1998 in order to facilitate its policy on road pricing (see *32* for a detailed description of the road pricing policy and the technologies involved) by better management of toll collections. This smart technology possesses continuous monitoring feature for real-time detection of the vehicles passing its sensors, which are installed on overhead gantries across the roads. Once a vehicle passes a gantry, tolls are automatically deducted from smart cards installed on the specifically designed in-vehicle unit (IU), without requiring the vehicle to slow down or stop. The ERP system is capable of managing multiple transactions at vehicle speeds of more than 120 km per hour. This automatic and fast transaction making capability along with the road pricing policy has been proven to be effective in reducing congestion, also in increasing average traffic speed to 40 to 45 km per hour from 30 to 35 km per hour under the old Area Licensing Scheme system, which featured a manually operated toll collection system (*33*).

Despite the success of the ERP, many operational and social challenges arose during its implementation (*32*, *33*). Similar to Hong Kong (*34*) and Netherlands (*35*), the privacy issue was the main public concern about the implementation of the ERP system. However, Singapore managed to overcome this challenge through proper public campaigns. The campaign motivated people by highlighting the ERP's potentiality on reducing congestions and obtaining a fully automated toll payment system. At the onset of implementation, another important challenge was to ensure that every vehicle is equipped with an IU to reduce the number of violations due to not having an IU. Singapore opted to distribute the IUs for free of charge for a certain period (*33*) so that every vehicle-owner voluntarily gets their vehicles fitted with the IUs before the ERP system starts its operation. Currently every new vehicle must have to be equipped with IU before it operates on roads. Hence Singapore has achieved a 100% usage of electronic toll payment. Similar system is also available in Hong Kong and Tokyo. However they do not have a law on the mandatory usage of IUs. Hence only 50% (*36*) of the Hong Kong vehicles and 83% (*37*) of the Tokyo vehicles use the electronic toll payment system.

With a successful operation of the ERP system for about 12 years, the LTA is now looking forward to upgrade it to its next generation (ERP II). Several technologies based on GPS are being studied to check their suitability (*22*). The GPS-based technology will be able to remove the need of physical gantries by introducing a distance-based congestion charging system.

CONCLUSION

This paper discussed the smart technology initiatives in the transportation system of Singapore for promoting and ensuring sustainability. Arising from the need for automating its transport system and implementing sustainable policies, Singapore has incorporated a wide range of smart technologies in its transport system. The basic idea is to have technological systems that reduce human involvement through accurate monitoring, fast processing, and reliable control, whilst enhancing the sustainability initiatives of its transport system.

Different issues of sustainable transport, such as enhancing mobility and accessibility, ensuring safety and social equity, improving system efficiency, protecting environment and fostering economy are addressed by utilizing the smart technologies. In general, the technologies facilitate implementation of different policies that lead towards achieving a sustainable transport system. Promoting public transport as a viable alternative to private transport with targets of reducing traffic flow, fuel consumption and emissions has been facilitated by many smart technologies, such as the bus priority signal system, bus lane enforcement system, availability of real-time service information and an integrated multi-modal fare payment technology. Availability of traffic and travel related information also have potential for enhancing motorists' flexibility in route planning so as to ensure a less congested, faster and safer trip. For enhancing safety of motorists and pedestrians at intersections, a set of smart traffic control systems is used which also increases efficiency of road networks and environmental health. The electronic toll payment system is another smart technology which has been successfully implemented to facilitate the road pricing policy for managing congestion. All these technologies act together for shaping the transportation system of Singapore as a sustainable one that promotes public transport, manages congestion, increases overall efficiency, reduces travel time and environmental emissions, and improves safety.

The Singapore experience on utilizing smart technologies in achieving a sustainable transport system shows that the technologies has enhanced overall safety and efficiency of the transport system. It also reflects that the associated authorities are committed to promote sustainability through utilization of more smart technologies. Indeed, the Singapore experience could be a useful reference for the cities those intend to promote and ensure sustainability in the development of the transport system.

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TABLE 1 Smart Technologies in the Transport System of Singapore and their Potential Influences on Sustainability

Categories of Smart Transport Technology	Smart Technologies in Singapore	Potential Influences on Sustainability
Control Systems *(manages traffic flow and safety at intersections)*	• Traffic signal system • Transit priority signal • Pedestrian signal • Elderly pedestrian signal • Intelligent road studs	• Higher system efficiency (optimized traffic flow) • Reduced fuel consumption and emission (less congestion) • Enhanced safety of motorists and pedestrians • Increased choice of modes (promoting public transport)
Monitoring and Enforcement Systems *(monitors traffic flow continuously to ensure proper enforcement of rules)*	• Intersection surveillance system • Speed cameras • Red light cameras • Incident detection and management system • Bus lane enforcement system	• Enhanced safety (smart surveillance) • Smoother traffic flow (less violation of rules, less incidents, less clearance time after incidents) • Higher choice of modes (promoting bus service)
Information Management Systems *(shares real-time traffic and travel information to motorists and passengers)*	• Traffic news broadcasting o Traffic flow and travel time o Accidents and incidents o Parking guidance o Dynamic information (signs, motorist's speed) • Public transport information sharing o Interactive service map (next-bus arrival time) o Travel planner o On-board passenger services o Taxi booking system	• Reduction of fuel consumption and emission (less congestion, less travel time) • Increased accessibility (smart taxi booking, public transport information availability) • Higher efficiency (availability of advisory information on travel planning and parking) and fostered economy
Revenue Management Systems *(processes fast and accurate transactions)*	• Integrated public transport fare payment system • Parking charge payment system • Electronic toll collection system	• Smoother traffic flow (fast transaction) • Integrated and affordable public transport • Less waste (no paper-based ticketing)

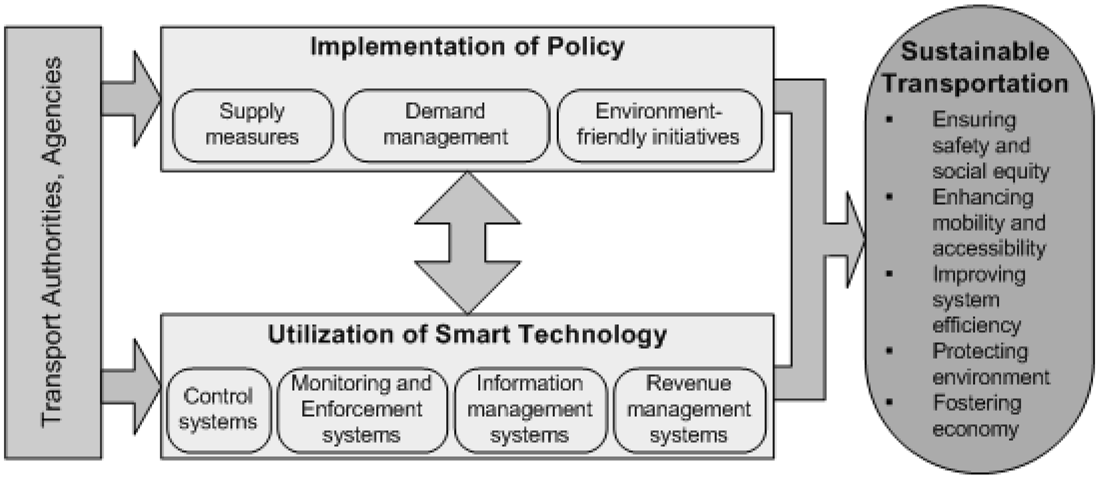

FIGURE 1 Embedding Smart Technology into a Sustainable Transport System