Sustainable Urban Transport

Smart Technology Initiatives in Singapore

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Achieving sustainability is a major goal of many urban transport systems. To attain an efficient, safe, and sustainable transport system, many innovative policies have been attempted in the past. Those policies often require smart technologies to assist in the implementation process and to enhance effectiveness. This paper discusses how sustainability can be promoted by embedding smart technologies in a modern transport system. In particular, this paper studies the transport system of Singapore to see how it 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 potential to address sustainability issues. The Singapore experience provides a useful reference for cities that intend to develop and promote a sustainable transport system.

Achieving sustainability has become a fundamental goal of many urban transport systems in the past two decades. The emerging concept of sustainability has promoted enormous interest among researchers and practitioners to develop a sustainable transport system (*1*). While many have focused on developing an appropriate definition of sustainable transport (*2–5*) and measures and indicators of sustainability (*6–10*) to assess whether a transport system is moving toward or away from sustainability, many others have put forward different strategies to make a transport system sustainable (*3, 11*). Defining sustainable transport and identifying indicators are important to make this concept more correct, focused, and measureable. However, the key to moving forward lies in identifying and developing strategies toward sustainability, because they are real steps in shaping a sustainable transport system.

A wide range of strategies has been proposed by many researchers and is being implemented in many cities in recent years. Some 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 environmentally friendly technologies. These strategies in general follow the three basic policy sets of transport system development—supply measures, demand management, and environmentally friendly initiatives—to seek a proper balance between the transportation and resource needs of current and future generations, which is the prime objective of 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 the efficiency of transport operations, while 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 policies is also influenced by advancements in technologies, and vice versa. Nijkamp illustrated how the policies and technology changes influence each other in development of sustainable transport by changing mobility patterns (*13*). Recent advancements in smart transport technologies allow transport authorities to develop and implement policies easily and efficiently by using those technologies. Therefore, development of policies and technologies are interdependent tasks for achieving sustainability in transport.

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

This paper explores the smart technology initiatives in the transport system of Singapore for promoting and ensuring sustainability.

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Transportation Research Record: Journal of the Transportation Research Board, No. 2243, Transportation Research Board of the National Academies, Washington, D.C., 2011, pp. 38–45.
DOI: 10.3141/2243-05

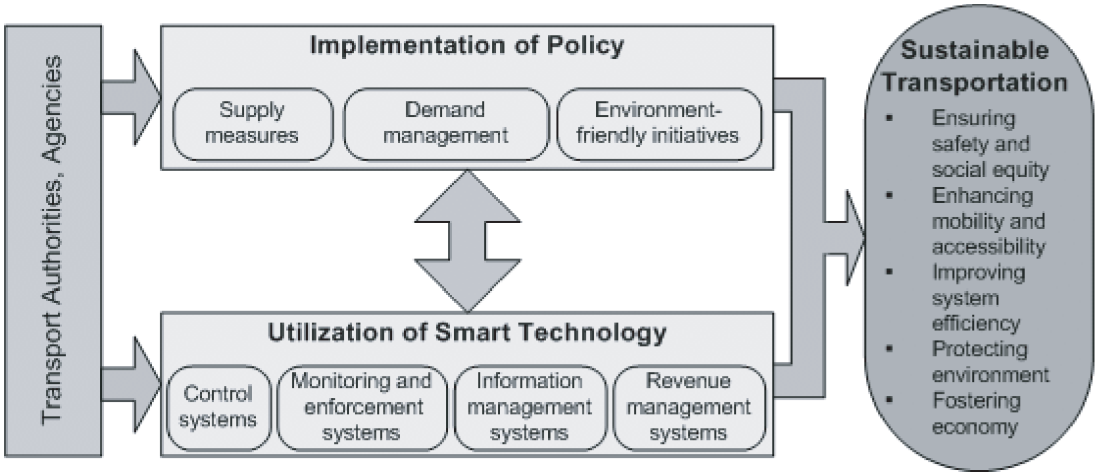

FIGURE 1 Embedding smart technology into a sustainable transport system.

In particular, it examines how the technologies address different issues of sustainability, such as protecting the environment, fostering the 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 in addressing sustainability through the use of 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 the system. Therefore, it is necessary to understand what constitutes sustainability and smartness in a transport system.

Sustainable Transport

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

Given this lack of a universally accepted definition, a popular approach for 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 Southeast Asia has also identified this deficiency and reported that most initiatives share common objectives, such as ensuring mobility, accessibility, and safety within environmental limits (*15*). May et al. proposed five desirable attributes of a sustainable transport system: liveable streets and neighborhoods, protection of the environment, equity and social inclusion, health and safety, and supporting a vibrant and efficient economy (*16*). Through a review of the literature, Castillo and Pitfield further showed that those commonly suggested attributes and practices of sustainable transport practices generally fit well with these attributes (*10*).

In developing the desirable attributes of a sustainable transport system, some have focused 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 (*5, 11, 18*) that includes most of the environmental, social, and economic concerns. The Centre for Sustainable Transport has also identified several attributes with respect to environment, society, and economy as a vision toward sustainable transportation by 2035 (*19*). In light of these attributes, a sustainable transport system can be defined as one that (*a*) allows for a safe and environmentally harmless basic means of access and development on the individual, business, and societal levels, while promoting equity within and between generations; (*b*) is reasonably priced and runs efficiently, providing a choice of transport mode as well as support for a competitive economy and good regional development; and (*c*) keeps production of emissions and waste within the carrying capacity of the natural environment and minimizes consumption of renewable and nonrenewable 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 transport systems more efficient through the use of smart technologies. A smart technology is a self-operative and corrective system that requires little or no human intervention. Typically, it has three elements (sensors, command and control unit, and actuators) to provide three basic capabilities (sensing, processing and decision making, and acting) (*20*). To have sensing ability, a smart technology has the capacity 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 on the state of the device, which are transmitted to a command and control unit for processing. The command and control unit is able to process and interpret the information received from sensors, make decisions on what to do next, and transmit 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 transmit it to a command and control unit; thus, a smart technology forms a closed-loop monitoring and action-taking process.

While many technologies in the transportation sector possess the three basic capabilities, smarter technologies are now 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 being advanced to possess higher-order capabilities, such as adaptability, self-optimization, interoperability, and predictability. Smart technologies should be aware of situations that occur frequently and should possess the adaptability to adjust performance in those situations, thus becoming able to learn from operations. Technologies also need to have abilities for self-optimization (i.e., be able to optimize 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 among devices in a network is an important aspect of a networked operation. Predictability is another higher-order ability a smart technology possesses. It has the ability to detect faults and to recover them 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 a transport system. However, there is clearly 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 the signal timings of all intersections in that network, whereas a red light enforcement camera is responsible only for detecting red light runners at a particular intersection. While the former requires all 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 latter requires only the enhanced capabilities. Because of the diversity in the purposes of using technologies, all technologies may not possess all the abilities outlined in 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 km^2 and 4.8 million inhabitants, as of 2008 (*21*). With the land constraint, it has a road capacity of 8,774 lane kilometers with 1,058 lane kilometers of expressways and 2,923 lane kilometers of major arterials, accounting for 12% of the total land area. It has controlled growth of motor vehicle ownership [see Han (*14*) for details of the associated policies], resulting in a total of about 0.9 million vehicles; 53% are private cars, 16% are motorcycles, and 1.7% are buses. With the controlled growth of motorized traffic, Singapore has been able to maintain average peak hour speeds of 63.3 and 26.7 km/h on expressways and arterials, respectively. As part of a people-centered public transport system, it maintains a world-class public transport network, which covers 118.9 km of mass rapid transit, 28.8 km of light rapid transit, and 3,268 bus fleets operating on 344 bus routes. The Land Transport Authority (LTA) of Singapore has put enormous effort into promoting public transport and making it a choice mode of travelers for advancing toward sustainability. It has targeted increasing 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 5,022 taxis in operation per million people.

Because of the land constraint, Singapore has mainly focused on innovations in policies and supporting technologies to meet the mobility needs of the people. With the introduction of smart technologies, it has been developing its transport system to be more efficient and sustainable. Use 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 the city level (i.e., that require an infrastructure system to become operational) are considered. The user-level technologies that do not require an infrastructure, such as smart vehicle control systems, collision avoidance systems, and driver safety monitoring systems are left out, because use of these technologies does not necessarily reflect the sustainability initiatives of a city's transport system; instead, it depends on the maker of the vehicles. Technological initiatives on environmentally friendly cars are also left out as they 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 potential ways to address sustainability in transport. The control systems manage traffic flow and safety at traffic intersections with physical infrastructure, such as traffic signals. Monitoring and enforcement systems ensure that motorists obey traffic rules through a set of surveillance systems. The information management systems collect, process, and share traffic and travel information with travelers through 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 following sections.

Control Systems

To ensure system efficiency and safety at traffic intersections, Singapore has taken initiatives in automating traffic control systems. They include an adaptive traffic signal system (GLIDE) for all the intersections in Singapore, which continuously collects traffic information and adjusts signal timing accordingly. Automatic detection of vehicles (by using wire sensors) and pedestrians (by using push buttons) at each approach allows each intersection to allocate green light 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 more smoothly and more efficiently at intersections as well as at the network level. Also, because there are fewer stops and less waiting time at intersections, fuel consumption and emission production decline.

TABLE 1 Smart Technologies in Transport System of Singapore and Their Potential Influence on Sustainability

Category of Smart Transport Technology	Smart Technologies in Singapore	Potential Influences on Sustainability
Control systems (manage 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 (monitor 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, fewer incidents, less clearance time after incidents) Higher choice of modes (promoting bus service)
Information management systems (share real-time traffic and travel information with motorists and passengers)	Traffic news broadcasting Traffic flow and travel time Accidents and incidents Parking guidance Dynamic information (signs, motorist's speed) Public transport information sharing Interactive service map (next-bus arrival time) Travel planner Onboard passenger services 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 (process 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)

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 provide the opportunity to change lanes. Introduction of the B signal has resulted in shorter bus journey times and enhanced reliability of buses as a viable alternative to private transport. While Singapore is utilizing the transit signal priority system to improve its bus services, many major cities in Asia (e.g., Hong Kong and Shanghai) have yet to implement it.

To enhance pedestrian safety at intersections, several technological initiatives have recently been taken. Elderly pedestrians, who may require more time to cross the road, are allocated additional green light time through a detection system, which requires them to tap their senior citizen concession card on card readers mounted on traffic light poles. Providing facilities for elderly pedestrians is a necessity as Singapore is facing the challenges of a fast-aging population. For instance, the old-age support ratio (number of people aged 15 to 64 years per person aged 65 years or older) dropped from 17 in 1970 to 8.2 in 2010. Green light 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, which alert motorists of pedestrians crossing the road by blinking the studs on the pavement when the green pedestrian signal is on (*23*). The road studs significantly improve safety for pedestrians and motorists at intersections, particularly 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 monitor transport facilities continuously by accurately sensing disturbances in traffic flow and identifying violations. A smart surveillance system will result in fewer rule violations, fewer incidents, and less clearance time after incidents, thus leading to smoother and safer traffic flow, which is important for an advanced economy. Examples of using smart technologies in traffic enforcement are discussed in the following paragraphs.

To ensure that motorists obey posted speed limits, Singapore uses automated laser-based speed cameras along with traditional handheld speed guns. Forty-five possible locations have installed speed cameras (as of July 2010), as listed by the traffic police (*24*). These cameras automatically detect speeding vehicles in real time and traffic police issue summons to the offending motorists. Reducing cases of speeding has great potential to improve safety on high-speed roads. While speed cameras are used to enforce the speed limit, variable speed limit signs are used to guide motorists to a smooth cruising speed. Variable speed limit signs are dynamic signs to display advisory speed limits based on changing traffic conditions.

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

To 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 centers monitor traffic conditions at intersections 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. About 280 cameras (as of May 2010) are in operation for managing traffic flow and enforcement at intersections (*23*).

In addition to intersections, surveillance cameras are being installed along 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 detect incidents and congestion automatically in real time and verifies them with a surveillance camera system. Real-time detection and verification allow for prompt activation of recovery vehicles and other authorities (e.g., traffic police) to ensure quick restoration of normal traffic flow, thus minimizing congestion and reducing 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 offenses, such as detecting offending parties in an incident. The EMAS service is currently available for expressways and will be extended to 10 major arterials by 2013 (*23*).

To promote bus service, several policies have been implemented, such as bus lanes, full-day bus lanes, and mandatory give way to buses; a detailed description of the policies is available elsewhere (*22*). In response to public feedback on problems in Singapore's public transport system (e.g., long waiting times, erratic bus arrivals), the LTA targeted increasing the network of bus lanes to 150 km and full-day bus lanes to 23 km by June 2008 from 120 and 7.6 km, respectively, in 2007 (*22*). These policies target improving the travel time of buses (increasing average bus speeds to 20 to 25 km/h by 2009). To regulate these policies, the LTA utilizes a smart bus lane enforcement system. It includes installing enforcement cameras onboard buses that travel along routes with bus lanes. A total of 90 buses on 12 routes were fitted with the cameras (in June 2008) to detect bus lane violations (*23*). With a little human intervention, the enforcement system is able to enhance bus lane and full-day bus lane policies to ensure priority for buses. These initiatives on providing priority to buses on roads enhance the effectiveness of the bus service and provide an alternative and affordable choice mode for travelers.

Information Management Systems

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

Traffic News Broadcasting

Travelers 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 data are obtained by combining the information collected from different smart systems, such as the EMAS, GLIDE, J-Eyes, and TrafficScan. TrafficScan is a smart system that uses travel information (location and speed) of taxis equipped with a Global Positioning System (GPS). It provides average travel time along roads to travelers so they can plan for a smoother journey. 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 is shared through different in-vehicle devices (e.g., radio, mobile media) and variable message signs along roads. Sharing of traffic information allows travelers to plan their routes in advance to avoid roads with congestion or accidents. Also, travel time displays along roads facilitate the route selection and modification process while traveling.

Different dynamic signs are also used to provide real-time information on individual motorists, such as Your Speed Sign, which displays motorists' speeds 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 that predicts traffic flow and speed using advanced statistical techniques. By utilizing historic and real-time traffic information, this tool currently (in the trial phase) can achieve 85% accuracy in predicting traffic volume and speed 10 min 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 will help transport authorities to divert traffic from congested roads to those less congested, thus increasing system efficiency.

To promote efficient use of parking facilities and to reduce the traveling time of searching for a parking lot, Singapore has developed a smart guidance system that disseminates 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 to display on roadside electronic information panels positioned at key locations. Currently, there are 24 panels displaying parking guidelines in the central business district (*23*). Motorists are able to make an informed decision on which car park to use while driving inside the central business district; thus, the parking guidance system reduces unnecessary travel time for parking space searching and the traffic flow in those areas.

Public Transportation Information Sharing

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

The integrated map service allows travelers to access information on multimodal transit alternatives to meet the needs of their door-to-door journey. Maps of bus and train services are available at stations, interchanges, and onboard. Travelers can also access information on real-time next-bus arrival times at many bus stops (76 bus stops were equipped with information display panels in 2008) to help manage their waiting times and make informed travel decisions

(*27*). Travelers can also access information on the Internet or with mobile phones [via small message service (SMS)]. The LTA planned to cover all bus stops with this service by March 2010 (*22*). As updated in June 2009, this service was provided for 215 bus stops (*28*). For train services, arrival time of the next train is available on platform display panels and in close proximity of stations.

The public transport travel advisor features a web-based door-to-door multimodal journey planner, launched in July 2008, which allows travelers to decide on their preferred routes (*27*). Through multimodal integration, it is able to search for the fastest, cheapest, or shortest route by combining different travel alternatives. Accessibility of the Internet on mobile phones has made this service available to travelers before they start a journey or during their journey. This journey planner improves accessibility and the appeal of public transport as a preferred mode for many travelers.

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

To bridge the gap between private and public transport by providing a high-end personalized service, Singapore maintains a world-class taxi service. To offer advanced and instantaneous booking service, different taxi service providers in Singapore use smart taxi booking systems. Passengers are able to book a taxi through the Internet (from home) and with a mobile phone call (on the road) to the contact centers of service providers. The contact centers wirelessly connect 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*). An SMS–based booking service is also available, which saves time on waiting for a call to be answered by a contact center and waiting for confirmation of a taxi. The SMS-based service is also useful for speech- and hearing-impaired passengers. While the phone-call-based booking is common in many Asian cities (e.g., Tokyo, Hong Kong, and Shanghai), only Singapore has an SMS-based booking system that can bypass operators in a contact center and that supports English. Singapore's smart taxi booking service helps to achieve the quality-of-service expectations—a waiting time of less than 5 min to confirm a taxi booking (in at least 90% of cases) and 10 min for a taxi to arrive once a booking is confirmed (in at least 85% of cases) (*30*).

Apart from the above initiatives taken to disseminate traffic information, the LTA is looking forward to using its second-generation electronic road pricing (ERP) system (ERP II) in collecting and disseminating traffic information. It is hoped that successful implementation of ERP II with GPS-based technology will open a wide range of opportunities to enhance information dissemination (*22*). ERP II will allow motorists to plan the time, mode, and route of their journeys in advance. It also possesses the 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 potentials will help to improve travel time savings and the overall efficiency of the road network.

Revenue Management Systems

Managing fast and accurate transactions is important for a transport system to be smarter and more efficient. Singapore uses 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 launched a 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 travelers to use a CEPAS (contactless e-purse application) card, which is a tap-and-go smart card for public transport fare payment, ERP payment, parking charge payment, and payments at many retail outlets (e.g., McDonald's restaurants, 7-Eleven). Before the SeP system, travelers were required to use different cards for paying public transport fares (the EZ link card) and other payment services (cash cards). The SeP features quick and accurate transactions to facilitate a faster boarding and alighting process on buses and trains, thus reducing the overall journey time. Introduction of the distance-based through-fare structure in July 2010 has made transfers more seamless and convenient by removing the existing fare penalty associated with each transfer, thus making the public transport system more integrated and affordable; further details are provided elsewhere (*31*).

Singapore has been using the ERP since 1998 to facilitate its policy on road pricing by managing toll collections better; a detailed description of the road pricing policy and the technologies involved is provided elsewhere (*32*). This smart technology possesses a continuous monitoring feature for real-time detection of the vehicles passing its sensors, which are installed on overhead gantries across 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/h. This automatic and fast transaction capability along with the road pricing policy has been effective in reducing congestion and in increasing average traffic speed to 40 to 45 km/h from 30 to 35 km/h 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 the Netherlands (*35*), the privacy issue was the main public concern about 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 potential to reduce congestion and obtain a fully automated toll payment system. At the onset of implementation, another important challenge was to ensure that every vehicle was equipped with an IU to reduce the number of violations due to not having an IU. Singapore opted to distribute the IUs free of charge for a certain period (*33*) so that all vehicle owners voluntarily had their vehicles fitted with IUs before the ERP system started operation. Currently, every new vehicle must be equipped with an IU before it operates on roads. Singapore achieved 100% usage of electronic toll payment. A similar system is available in Hong Kong and Tokyo. However, they do not have a law about mandatory usage of IUs. Only 50% of Hong Kong vehicles (*36*) and 83% of Tokyo vehicles (*37*) use the electronic toll payment system.

With successful operation of the ERP system for about 12 years, the LTA is now looking forward to upgrading 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 for physical gantries by introducing a distance-based congestion charging system.

CONCLUSION

This paper discusses the smart technology initiatives in the transport system of Singapore for promoting and ensuring sustainability. Arising from the need to automate its transport system and implement 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, while enhancing the sustainability initiatives of the transport system.

Different issues of sustainable transport, such as enhancing mobility and accessibility, ensuring safety and social equity, improving system efficiency, protecting the environment, and fostering economy are addressed by utilizing the smart technologies. In general, the technologies facilitate implementation of different policies that lead toward 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 multimodal fare payment technology. The availability of traffic- and travel-related information can also enhance motorists' flexibility in route planning to ensure a less congested, faster, and safer trip. To improve the safety of motorists and pedestrians at intersections, a set of smart traffic control systems is used that also increases the efficiency of road networks and environmental health. The electronic toll payment system is another smart technology that has been successfully implemented to facilitate the road pricing policy to manage congestion. These technologies act together to shape the transport 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 in utilizing smart technologies to achieve a sustainable transport system shows that the technologies have enhanced the overall safety and efficiency of the transport system. It also shows that the associated authorities are committed to promote sustainability through utilization of more smart technologies. The Singapore experience could be a useful reference for cities that intend to promote and ensure sustainability in developing a transport system.

ACKNOWLEDGMENT

The authors gratefully acknowledge the Ministry of Education Academic Research Fund Tier 1 funding for this research.

REFERENCES

1. World Commission on Environment and Development. *Our Common Future.* Oxford University Press, Oxford, United Kingdom, 1987.
2. Black, W. R. Sustainable Transportation: A U.S. perspective. *Journal of Transport Geography,* Vol. 4, No. 3, 1996, pp. 151–159.
3. Greene, D. L., and M. Wegener. Sustainable Transport. *Journal of Transport Geography,* Vol. 5, No. 3, 1997, pp. 177–190.
4. Steg, L., and R. Gifford. Sustainable Transportation and Quality of Life. *Journal of Transport Geography,* Vol. 13, No. 1, 2005, pp. 59–69.
5. Mitropoulos, L., P. D. Prevedouros, and E. G. Nathanail. Assessing Sustainability for Urban Transportation Modes: Conceptual Framework. Presented at 89th Annual Meeting of the Transportation Research Board, Washington, D.C., 2010.
6. Black, J. A., A. Paez, and P. A. Suthanaya. Sustainable Urban Transportation: Performance Indicators and Some Analytical Approaches. *Journal of Urban Planning and Development,* Vol. 128, No. 4, 2002, pp. 184–209.
7. *Sustainable Transportation Performance Indicators. Report on Phase 3.* Centre for Sustainable Transportation, Toronto, Ontario, Canada, Dec. 31, 2002. http://cst.uwinnipeg.ca/documents/STPI%20Phase%203%20report.pdf. Accessed July 15, 2010.
8. Litman, T. *Developing Indicators for Comprehensive and Sustainable Transport Planning.* Victoria Transport Policy Institute, Victoria, British Columbia, Canada, 2009. http://www.vtpi.org/sus_tran_ind.pdf. Accessed July 25, 2010.
9. Nichols, J., N. Garrick, and C. Atkinson-Palombo. Framework for Developing Indicators of Sustainability for Transportation Planning. Presented at 88th Annual Meeting of the Transportation Research Board, Washington, D.C., 2009.
10. Castillo, H., and D. E. Pitfield. ELASTIC—A Methodological Framework for Identifying and Selecting Sustainable Transport Indicators. *Transportation Research Part D,* Vol. 15, No. 4, 2010, pp. 179–188.
11. Goldman, T., and R. Gorham. Sustainable Urban Transport: Four Innovative Directions. *Technology in Society,* Vol. 28, No. 1–2, 2006, pp. 261–273.
12. Towards Sustainable Transportation. *Organisation of Economic Co-operation and Development Proceedings, The Vancouver Conference,* Vancouver, British Columbia, Canada, March 24–27, 1996.
13. Nijkamp, P. Roads Toward Environmentally Sustainable Transport. *Transportation Research Part A,* Vol. 28, No. 4, 1994, pp. 261–271.
14. Han, S. S. Managing Motorization in Sustainable Transport Planning: The Singapore Experience. *Journal of Transport Geography,* Vol. 18, No. 2, 2010, pp. 314–321.
15. Jeon, C. M., and A. Amekudzi. Assessing Sustainability in Transportation Systems: Definitions, Indicators, and Metrics. *Journal of Infrastructure Systems,* Vol. 11, No. 1, 2005, pp. 31–50.
16. May, A. D., T. Jarvi-Nykanen, H. Minken, F. Ramjerdi, B. Mathhews, and A. Monzon. *Cities' Decision-Making Requirements—PROSPECTS Deliverables 1.* Institute of Transport Studies, University of Leeds, Leeds, United Kingdom, 2001.
17. *Transport/Telecommunications.* 2340th Council Meeting, 7587/01 (Presse 131). European Council of Ministers of Transport, Luxembourg City, Luxembourg, April 2001. http://corporate.skynet.be/sustainablefreight/trans-counci-conclusion-05-04-01.htm. Accessed July 24, 2010.
18. Hull, A. Policy Integration: What Will It Take to Achieve More Sustainable Transport Solutions in Cities? *Transport Policy,* Vol. 15, No. 2, 2008, pp. 94–103.
19. *Definition and Vision of Sustainable Transportation.* Centre for Sustainable Transportation, Toronto, Ontario, Canada, Oct. 2002. http://cst.uwinnipeg.ca/documents/Definition_Vision_E.pdf. Accessed July 12, 2010.
20. Akhras, G. Smart Materials and Smart Systems for the Future. *Canadian Military Journal,* Vol. 1, No. 3, 2000, pp. 25–32.
21. *Land Transport Statistics in Brief 2009.* Land Transport Authority, Singapore, 2009. http://www.lta.gov.sg/corp_info/doc/Statistics%20in%20Brief%202009.pdf. Accessed July 26, 2010.
22. *Land Transport Master Plan.* Land Transport Authority, Singapore, 2008.
23. *One Motoring. On the Roads.* Land Transport Authority, Singapore. http://www.onemotoring.com.sg/publish/onemotoring/en/on_the_road.html. Accessed July 15, 2010.
24. *Information—Police Speed Camera Locations.* Singapore Police Force, Singapore, 2009. http://driving-in-singapore.spf.gov.sg/services/Driving_in_Singapore/information_misc_speedcamera.htm. Accessed July 15, 2010.
25. Haque, M. M., H. C. Chin, and H. L. Huang. Examining Exposure of Motorcycles at Signalized Intersections. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2048,* Transportation Research Board of the National Academies, Washington, D.C., 2008, pp. 60–65.

26. *MyTransport.sg.* Land Transport Authority, Singapore, 2009. http://www.publictransport.sg/publish/ptp/en/mytransportsg.html. Accessed July 26, 2010.
27. *LTA Annual Report 2008/2009.* Land Transport Authority, Singapore, 2009. http://www.lta.gov.sg/corp_info/annual_report_0809/index.htm. Accessed July 24, 2010.
28. *List of Bus Stops with Bus Arrival Information.* Land Transport Authority, Singapore. http://www.publictransport.sg/publish/etc/medialib/test2.Par.77895.File.dat/List%20of%20Bus%20Stops%20for%20mobile.pdf. Accessed July 25, 2010.
29. *News Releases: One Common Taxi Number.* Land Transport Authority, Singapore, 2003. http://app.lta.gov.sg/corp_press_content.asp?start=1970. Accessed July 19, 2010.
30. *News Releases: Improving Taxi Service Levels New Licensing Framework for Taxi Companies.* Land Transport Authority, Singapore, 2003.http://app.lta.gov.sg/corp_press_content.asp?start=666. Accessed July 20, 2010.
31. *Distance Fares.* PublicTransport@SG, Singapore, 2009. http://www.publictransport.sg/publish/ptp/en/distance_based_fares.html. Accessed July 12, 2010.
32. Goh, M. Congestion Management and Electronic Road Pricing in Singapore. *Journal of Transport Geography,* Vol. 10, No. 1, 2002, pp. 29–38.
33. Foo, T. S. An Advanced Demand Management Instrument in Urban Transport: Electronic Road Pricing in Singapore. *Cities,* Vol. 17, No. 1, 2000, pp. 33–45.
34. Hau, T. D. Electronic Road Pricing: Developments in Hong Kong 1983–1989. *Journal of Transport Economics and Policy,* Vol. 24, No. 2, 1990, pp. 203–214.
35. Phang, S.-Y., and R.-S. Toh. From Manual to Electronic Road Congestion Pricing: The Singapore Experience and Experiment. *Transportation Research Part E,* Vol. 33, No. 2, 1997, pp. 97–106.
36. *Automatic Toll Collection System.* Transport Department, Hong Kong, 2009. http://www.td.gov.hk/en/transport_in_hong_kong/its/its_achievements/automatic_toll_collection_system/index.html. Accessed Nov. 11, 2010.
37. *Initiatives to Ensure Safety, Security and Comfort.* Ministry of Land, Infrastructure, Transport and Tourism, Tokyo. http://www.mlit.go.jp/road/road_e/pdf/chapter02.pdf. Accessed Nov. 11, 2010.

This paper does not reflect the views of any organizations or agencies mentioned here. The authors are responsible for the views of this paper.

The Intelligent Transportation Systems Committee peer-reviewed this paper.