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SUSTAINABLE, SAFE, SMART—THREE KEY ELEMENTS OF SINGAPORE'S EVOLVING TRANSPORT POLICIES

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ABSTRACT
Sustainability, safety and smartness are three key elements of a modern transportation system. This study illustrates various policy directions and initiatives of Singapore to address how its transportation system is progressing in light of these three components. Sustainability targets economical efficiency, environmental justice and social equity by including policies for integrating land use and transport planning, ensuring adequate transport supply measures, managing travel demand efficiently, and incorporating environment-friendly strategies. Safety initiatives of its transportation system aim to minimize injuries and incidents of all users including motorists, public transport commuters, pedestrians, and bicyclists. Smartness incorporates qualities like real time sensing, fast processing and decision making, and automated action-taking into its control, monitoring, information management and revenue collection systems. Various policy implications and technology applications along these three directions reveal that smart technologies facilitate implementation of policies promoting sustainability and safety. The Singapore experience could serve as a good reference for other cities in promoting a transportation system that is sustainable, safe and smart.

Key Words: Sustainability; Smartness; Safety; Urban Mobility; Singapore

1. INTRODUCTION

1.1 Urban Mobility

Mobility in an urban area is a complex system because of having many inter-related and interconnected human activities and interactions. It is, therefore, often desired a competent transportation system that can accommodate various travel needs efficiently. In the past, the efficiency of a transportation system was used to be improved by providing more transport supplies like construction of new roads, expansion of highway/rail networks and increasing the number of transport facilities. As a result, urban mobility suffered from many inevitable problems like urban sprawl, high private automobile usage and congestion and consequently became unsustainable in many ways.

In recent years, sustainability of a transportation system has become enormously important mainly because of increasing concerns on environmental issues and climate change. Emissions from vehicles contribute to ambient concentrations of carbon dioxide (CO_2) and other air pollutants such as carbon monoxide, sulphur dioxide, nitrogen dioxide and fine particulates. According to the International Energy Agency (IEA), the transport sector contributed to about one-fourth of the total CO_2 emissions in the world (Schipper et al., 2009). In US and Singapore, the corresponding CO_2 emissions by the transport sector were respectively about 37% and 19% (Button, 2009; LTA 2008a). Statistics on air pollutant emissions in US and Europe showed that about half of oxides of nitrogen, nearly two-fifths of volatile organic compounds and more than two-third of carbon monoxide emissions were produced by motor vehicles alone (Greene and Wegener, 1997).

Besides environmental issues, other intractable problems of a land transport system include traffic fatalities and injuries, congestion, noise pollution, depletion of resources, and inaccessibility to facilities. Traffic accidents and congestion impose a huge economic burden to the society. For example, the total costs of traffic accidents in Singapore was about S$610.3 million for the year 2003 which was about 0.34% of the annual GDP (Chin et al., 2006). The congestion cost in US was about US$78 billion annually in the form of 4.2

billion lost hours and 2.9 billion gallons of wasted fuel (Texas Transportation Institute, 2008). Congestion also results in increased emissions of green house gases and air pollutants. Faster depletion of non-renewable fossil fuels and unavailability of lands in urban areas are also among the major obstacles to develop an efficient urban mobility system.

To tackle the land transport problems, many strategies and policy directions have been developed and exercised over the years. These include integrating land use and transport planning (Sim et al., 2001), designing compact-city plans (Sung and Choo, 2010), implementing transit-oriented developments (Sung and Oh, 2011), controlling the growth of motorization (Han, 2010), managing travel demand through pricing and financing (Tuan Seik, 2000), promoting public transport (Ibrahim, 2003), increasing walking and cycling facilities (Duduta et al., 2010), and incorporating environment-friendly technologies (Lopez-Ruiz and Crozet, 2010). It is obvious that these strategies and policies are helpful to create a sustainable transportation system that seeks a proper balance between transportation needs and available resources within and between current and future generations. However, a clear vision of a transport system often remains inherent. A clear vision is extremely important for identifying and developing appropriate strategies and policies to build an efficient, long-lasting and safe transport system.

Since the definition of ‘sustainable transport’ is complex because of its social, technical and economic components, the concept of sustainable transport planning is usually framed by articulating principles and desirable attributes. For example, May et al. (2001) proposed six overarching objectives of a sustainable transport system such as (1) economic efficiency, (2) livable streets and neighborhoods, (3) protection of the environment, (4) equity and social inclusion, (5) health and safety, and (6) contribution to economic growth. Using these objectives, Castillo and Pitfield (2010) subsequently developed an evaluative and logical approach to identify and rank sustainable transport indicators based on measurability, availability, and interpretability. A close observation on the identified top fifteen indicators showed that managing traffic volume, encouraging cycling trips, promoting public transport, reducing CO_2 and air pollutant emissions, and lowering traffic accidents were the key indicators of sustainability. In terms of activity, sustainability policies for an urban mobility system had been found to be divided into four clusters: new mobility, city logistics, intelligent system management, and livability (Goldman and Gorham, 2006).

It appears that safety and smartness have been conceptualized as desirable attributes or indicators of sustainability. However, considering these two as attributes of sustainability may lower the importance of their inclusion into the vision and missions of future urban mobility system. Traffic fatalities and injuries are a serious public health issue, and therefore visions for safety are enormously important to ensure a system’s viability and to minimize the threats to public health. The incorporation of smartness into the urban mobility system is important mainly because of three reasons: (1) it increases the efficiency and reliability of the system, (2) it increases the comfort of the commuters, and (3) it helps to promote sustainability and safety policies. This paper illustrates with an example of Singapore to show how a modern transportation system is progressing with the visions for sustainability, safety and smartness inside its urban mobility system.

1.2 Policy Directions of Singapore

Singapore is a small city-state island country with land area of 710.2 sq. Km and 4.8 million inhabitants making the population density of 6,814 people per sq. km. The road network of

Singapore covers 3,325 km of paved roads including 161 km of expressways and the rail network covers about 148 km. Due to having a strong economy, it generates huge motorized journeys of about 9.86 millions every day and the public transport demand stands for more than half (56%) of these trips (LTA, 2009a). To handle this travel demand efficiently, it has mostly capitalized on its strong political will to develop suitable and innovative strategies and policies into the transport system on its path towards a livable and vibrant global city. A close observation on these policies and initiatives reveals that there are mainly three components of its evolving land transport policies which are Sustainability, Safety, and Smartness.

Sustainability has become the fundamental component of transport planning and policy implications recently. At the same time, safety should not be ignored to have a feasible transportation system. In addition, recent technological revolutions have made smart or intelligent technologies readily available to be incorporated inside the transportation system to make it more efficient to users while maintaining and/or improving sustainability and safety. A modern transportation system along these three key components can be defined as "a system that promotes social and economic welfare in a safe and efficient way without damaging the environment or depleting environmental resources". An overview of transport policies of Singapore along with major components and associated targets is depicted in Figure 1.

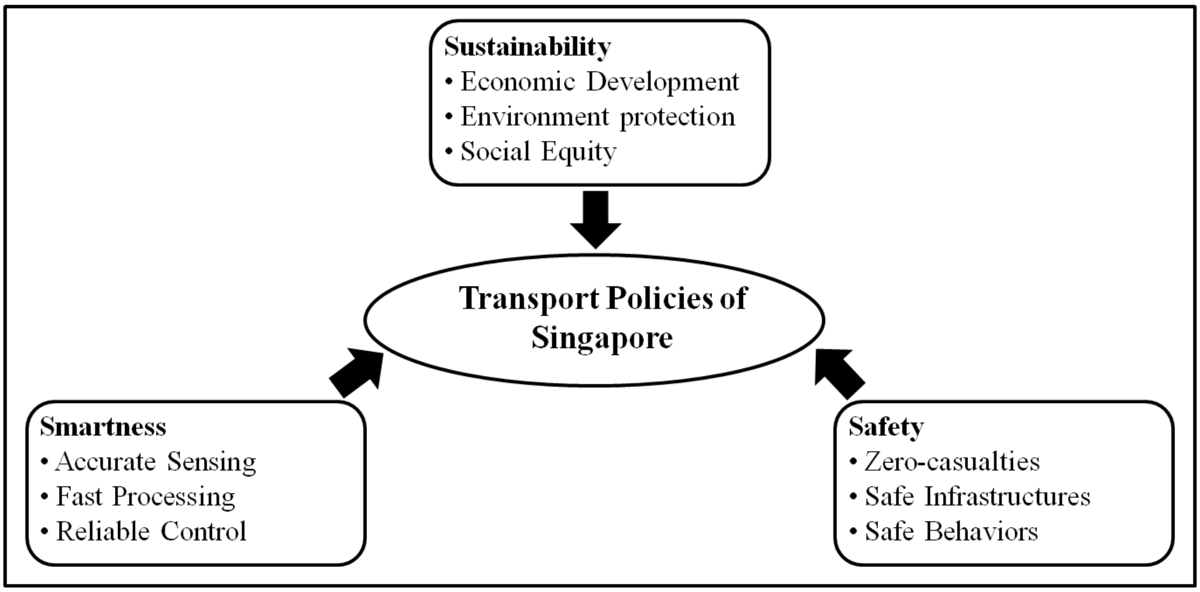

Figure 1: Major policy directions of Singapore's evolving transport policies

The first component of these three is sustainability. ECMT (2001) has defined a sustainable transport system 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 keeps the consumption of renewable resources and non-renewable resources respectively within the rates of generation and development of renewable substitutes, while minimizing the impact on the use of land as well as production of noise. In light of this, it has three major targets: 1) economic development, 2) environment protection, and 3) social equity.

The second component is safety that ensures viability of the system. Road safety is an important public health issue and traffic incidents are not only costly to the injured, but also a burden to the society and the national health system. Since a transportation system is dynamic and has human interactions, incidents are an inevitable consequence. Therefore, a transport system should be focused on minimizing the injuries and casualties of its users, promoting safe road usages through the development of proper infrastructures and environment, and encouraging safe road behaviors through education and legislations. Note that sustainability and safety may fit together well because they both describe how a transportation system addresses its adverse and unintended consequences. Policies, however, are often strategized to tackle these two individually and hence have been kept as two separate components.

Smartness is the third component that utilizes smart technologies to achieve greater economical and environmental efficiency. Various strategies have been developed and implemented to embed these smart technologies into the urban transportation system of Singapore. A smart technology is defined as a self-operative and corrective system that requires little or no human intervention. It has three basic elements – sensors, command and control unit, and actuators, contributing to three basic capabilities - sensing, processing and decision making, and acting (Akhras, 2000). Having sensing ability, a smart technology is capable to process and interpret the sensed information by using the command and control unit and to execute decisions into actions through actuators. These activities follow a cyclic pattern and make a smart technology forming a closed-loop monitoring and action-taking process.

1.3 Objective

In light of the above, it appears that sustainability, safety, and smartness are three important policy directions of the urban mobility system of Singapore. The objective of this study is to illustrate how the transportation system of Singapore is progressing along these three directions. Examining the transport policies and strategies of Singapore by categorizing them into these three elements is the key contribution of this study. In subsequent sections, this paper discusses key steps and initiatives of the transportation system of Singapore on its pathway to achieve sustainability, safety, and smartness. Lastly, the paper highlights some significant lessons learnt from the Singapore experience, identifies few shortcomings, and recommends some suggestions for the development of a better mobility framework of an urban transportation system.

2. SUSTAINABLE TRANSPORT PLANNING

A sustainable transport system mainly caters the mobility needs of the current and future generations to support economical activities while minimizing their impact on the environment. Policies and strategies to address sustainability on the land transport development of Singapore can be broadly categorized into four key areas: 1) integration of land use and transport planning, 2) transport supply measures, 3) transport demand management, and 4) incorporation of environment-friendly technologies for vehicles.

2.1 Integration of land use and transport planning

Singapore's small land area has consistently been a major constraint on land use and transport planning and hence an optimal balance and integration among these are required. It has mainly been achieved by incorporating a transit-oriented planning concept into its land use and transportation development. The first strategic development plan in 1971 decentralized population by developing residential blocks away from the Central Business District (CBD) and connected by roads, expressways, and Mass Rapid Transit (MRT) lines. Later, the revised concept plan of 1991 (LTA, 1996) was aimed to further decentralize commercial and economic activities by developing regional and sub-regional centers around MRT stations, following the constellation concept or hub-and-spoke model. Locating employment centers, industrial estates, business parks, and commercial centers near residential areas reduce the people's need for travel, while resulting in a good utilization of the MRT network.

For a better integration, a hierarchical system with well-defined roles for each transport mode has also been designed. While railways serve the long-haul travel, Light Rapid Transit (LRT) and buses provide feeder services to connect areas in housing states to MRT stations. Moreover, developments of high density residential blocks on high-rise buildings at and around major transport nodes such as MRT stations and bus interchanges have increased the convenience of commuters of those blocks by providing major transportation hubs within their walking distances and thus have reduced the demand of feeder services. These strategic plans have not only restricted the development of urban sprawl but also reduced the number and length of trips of commuters and hence are the key steps towards sustainability.

2.2 Transport supply measures

To ensure a livable and vibrant global city, Singapore has planned various transport supply measures to cope with the travel needs of current as well as future generations. An estimate shows that the projected increase in population and economic activities may increase the daily travel demand from the current 8.9 million to about 14.3 million journeys by the year 2020 (LTA, 2008a). To meet the mobility needs of people in a sustainable way, transport authorities are planning to increase the public transport mode share during the morning peak hours from 63% in 2008 to 70% by 2020, and also to double the public transport trips (from current 5 million to about 10 million) by 2020. Therefore, promoting public transport services including rapid transit system, buses and taxis are the main focus of the recent land transport master plan (LTA, 2008a). Other ancillary means of transportation supply include the implementation of the Park and Ride Scheme, provision of better pedestrian walkways and bicycling facilities and all the while ensuring accessibility for the various road users.

2.2.1 Rapid Transit System (RTS)

The current 148 km long RTS network consists of four MRT lines (68 stations) and three LRT lines (33 stations) that accommodate about 1.7 million passenger trips daily (LTA, 2009a). Ibrahim (2003) reported that more than 60% of Singaporeans use the MRT for commuting and other trips. To accommodate the projected demand of ten million trips on public transports, the MRT network has been planned to be doubled to 278 km by 2020 including two new lines and two extensions on existing lines that will introduce another 36 new MRT stations leading to the RTS density per million people from 31 km today to 51 km. Commuters on the central area will have an access to a RTS station within 400m or five minutes' walk. Comfort and convenience of the commuters will also be increased by providing more frequent MRT services. Although the average maximum passenger loading (3.7 pax/sqm) on the trains is already lower than other cities like Hong Kong (4.0 pax/sqm) and London (5.0 pax/sqm), the transport authority is looking forward to cooperate with operators to enhance capacity of the existing lines by increasing the frequency of trains

(LTA, 2008a). Overall, commuters will enjoy better connectivity and more comfortable rides in the trains, which at the same time help to reduce pressure on the roads.

2.2.2 Buses

Singapore's two bus operators currently operate a fleet of 3,268 buses on about 344 bus routes accommodating an average daily ridership of about 3.09 million (LTA, 2009a). The quality of the bus services is strictly maintained by an independent regulatory body, namely Public Transport Council (PTC). PTC standards and guidelines for buses include bus route design, bus stop locations, service frequencies and safety (Han, 2010). To further improve the connectivity of feeder services to the public transport hubs, PTC has initiated a new standard that requires bus operators to run at least 90% of their feeder bus services at frequencies of not more than 10 minutes during weekday peak periods (PTC, 2010).

To improve bus services, Land Transport Authority (LTA) is continuously developing and implementing various measures including peak hour bus lanes, full day bus lanes, priority at signalized junctions, and mandatory give way to exiting buses from bus bays. Some of these initiatives are pictorially shown in figure 2. As in 2008, there were a total of 155 km of peak hour bus lanes and 23 km of full day bus lanes in this island. A case study showed that the average bus speed on full day bus lane had been increased by 10% on weekdays and 23% on weekends (OM, 2011). A total of 202 bus stops in important locations has been equipped with ‘mandatory give way to exiting buses scheme’ that has made compulsory for motorists to give way to buses leaving bus bays. A trial showed that the delay of buses exiting bus bays had been reduced up to 73% in some cases (OM, 2011). LTA is further looking for other bus priority measures like contra-flow bus lanes and bus rapid transit system.

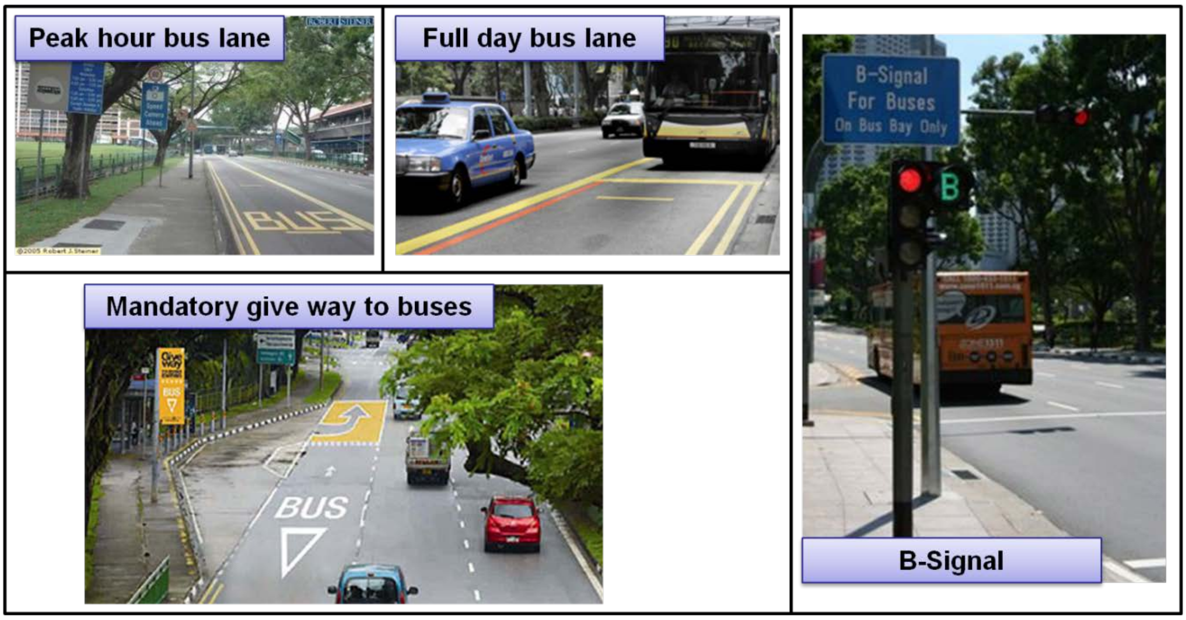

Figure 2: Schemes to improve bus operations

In addition to normal bus services, many special services have been introduced over the years to cater diverse needs of people especially who prefer a more comfortable and luxurious level of service. These include premium bus services, express bus services, intra town services, night bus services, and niche public bus services.

2.2.3 Integrated rail and bus services

To make journeys on public transport seamless and convenient, there has been a deliberate move towards integrating rail and bus services through coordinating service network, physical facilities, fares, and information system. Bus stations are strategically located near MRT stations and connected with well designed walkways for the convenience of commuters (see figure 3). A common ticketing system in the form of a universal fare card ("EZ-link") is available for fare payments on both trains and buses. To develop a more commuter-centric approach focusing on the 'total journey' experience of the commuters, LTA has recently taken the role of central bus network planner from the bus operators (LTA, 2009b). This initiative has mainly been targeted to reduce circuitous movement of buses by providing more direct and frequent feeder services to the major transfer hubs while promoting hub-and-spoke model. To further improve transfers, a distance-based through fare structure has been implemented in 2010 to remove current fare penalty associated with bus-rail or bus-bus transfers (LTA, 2009c). An integrated information system has also been developed to assist public transport users in planning their journeys. Various features of the information system will be briefly discussed in section 4.3.

Figure 3: Integration between rail and bus services

2.2.4 Taxis

Taxis bridge the gap between basic public transport modes and private cars by offering commuters a choice to have personalized high-end door-to-door services. Currently, there are 7 private taxi companies with a total fleet of 24,300 taxis catering for about 0.8 million trips daily. While fares and supply are maintained by individual companies, quality standards are regulated and enforced by the LTA. Taxi stands are strategically located in the CBD so that there is a taxi stand within a walking distance of five minutes from all buildings in the CBD.

2.2.5 Supplementary measures to improve the usage of public transport

Supplementary facilities to improve the usage of public transport include pedestrian walkways, bicycling facilities, and park-and-ride scheme. LTA maintains well designed footpaths, sheltered link ways, overpasses and underpasses to provide pedestrians a comfortable and conducive walking environment between transport nodes and residential, commercial and institutional buildings, as well as serving as connections between the various transport modes themselves. Cycling facilities have also been attempted to improve so that commuters can enjoy a better link to major transport nodes. Most of the MRT stations and bus interchanges have bicycle parking facilities that encourage interested commuters to cycle from the housing estates to public transport nodes. To further promote this environment-friendly mode, MRT and buses now allow foldable bicycles on board. Another supplementary measure to promote public transport is the park-and-ride scheme that allows motorists to park their vehicles in park-and-ride sites and take public transport to travel to the CBD. Singapore has currently 41 major park-and-ride sites that are strategically located near major transport hubs, such as MRT stations or bus interchanges around the CBD (LTA, 2009d).

The relationship of a transportation system to society, often referred as livability, is also vital in maximizing its usage. The livability mainly includes the allocation and design of public space, concern for accessibility, and opportunities for social engagement and recreation (Goldman and Gorham, 2006). Currently there are a number integrated public transport hubs including five bus-MRT interchanges and two MRT stations where air-conditioned bus interchanges and MRT stations are co-located with retail and commercial activities (LTA, 2008a). LTA has planned to build another five integrated interchanges where more retail spaces would be allocated to promote vibrancy on these hubs by allowing more public engagement. These transport hubs provide an added convenience to commuters by integrating transport planning with social needs—such as shopping on their way to a journey, accessible meeting points among family and friends, and recreational activities.

2.2.6 Meeting diverse needs of people

Equity is a key component of a sustainable transport system which must be ensured by providing sufficient transportation needs for various road user groups including elderly and physically challenged people. For these groups of people, bus stops and MRT stations as well as buses and trains are being redesigned to have wheelchair accesses. It has been targeted that 100% public buses will have wheelchair access facilities by 2020 (LTA, 2008a). Buses and trains have also been equipped with priority seats to facilitate passengers with special needs—such as handicapped, senior citizens, pregnant ladies and passenger carrying babies. Island-wide initiatives have been aimed to ensure barrier-free walkways for elderly and physically challenged people. These include widening footpaths to ensure a minimum 1.0m to 1.5m lateral clearance, providing at-grade pedestrian crossings, installing tactile guidelines and thickened road crossing lines for vision-impaired, and fitting audio-alert crossing facilities for hearing-impaired.

2.3 Transport demand management

Enhancing transport supply alone is not sufficient to maintain a smooth flow of traffic, especially since continuous road addition is unfeasible in land-scarce Singapore. Transport demand management policies also play a vital role in achieving sustainability that has mainly been done by controlling the growth of motorization and imposing road pricing policies.

2.3.1 Controlling growth of motorization

Singapore is maintaining a sustainable growth rate of its vehicle population by the vehicle quota system (VQS) policy since 1990. The VQS works by determining a suitable number of new vehicles allowed for registration annually and subsequently letting market forces determine the price of ownership via bidding. Using the VQS, the vehicle growth rate has been kept in tandem with the rate of road development. The rate of road development from 1990 to 2006 was about 1.0% p.a. but it is projected to be only 0.5% p.a. over the next 15 years. Therefore, the vehicle growth rate has also been lowered from 3.0% to 1.5% p.a. to ensure long term sustainability (LTA, 2008a).

In light of high costs of owning a car due to the VQS, the off-peak car (OPC) scheme has been developed to offer cars at a cheaper rate by allowing lower car registration fees and road taxes. OPCs are not allowed on roads from 7:00 am to 7:00 pm on weekdays and thus they do not contribute to traffic congestions. The OPC scheme is getting popular to Singaporeans as a statistic showed that there was a nine-fold increase of OPCs over five years from 2004 to 2008, and the share of OPCs was about 8% of the total car population (OM, 2010).

2.3.2 Imposing road pricing

In addition to purchase-based constraints, road pricing is a usage-based tax system mainly to reduce congestion by discouraging travel on expressways and major arterials towards CBD during peak hours. Congestion prices are collected by an electronic road pricing (ERP) system that functions with overhead gantries across roads and smart cards installed into in-vehicle units. ERP is capable to collect charges at operating speed. Through regular reviews and rate adjustments, ERP system has brought a more even flow of traffic by varying road charges according to time and place, depending on the level of congestion (e.g., Tuan Seik, 2000). ERP has been effective in maintaining an optimal speed range of 45 to 65 km/h on expressways and 20 to 30 km/h along arterial roads. The technology for road pricing will soon be updated ("ERP II") with the incorporation of Global Positioning System (GPS) or Global Navigational Satellite System (GNSS) technology that enables distance-based congestion charging instead of point charging with physical gantries. Therefore, congestion charges will be imposed based on the actual length of congested roads traversed by the motorists (LTA, 2008a). It will be a more flexible and reasonable method of managing and charging congestion, and thus is likely to be more effective and sustainable.

2.4 Incorporation of environment-friendly technologies and policies

To address environmental sustainability, various strategies and policies are incorporated into the transportation system—such as setting higher emission standards for vehicles and encouraging the use of cleaner fuels and green vehicles.

Through strict emission regulations, Singapore's ambient concentration of most air pollutants has been kept within international standards except for particulate matters smaller than 2.5 microns in size (PM2.5). To restrict these particles, more stringent emission standards (Euro IV) will be implemented for all vehicles by 2020 leading to about 70% less PM2.5 than current time (LTA, 2008a). LTA is also working with bus operators and taxi companies so that all taxis will be of Euro IV standard by 2014, while all public buses will be so by 2023 or if possible by 2020.

Another policy to control emissions is the surcharge tax for older vehicles. Vehicles older than 10 years are subjected to a surcharge tax on their annual road taxes charging about 10%, 30% and 50% for vehicles respectively over 10, 12 and 14 years old (LTA, 2003). This is to encourage motorists to use newer vehicles with better emission technology, as older vehicles tend to contribute more to pollution. From 2007, the more stringent Chassis Dynamometer Smoke Test has also replaced the Free Acceleration Smoke Test for mandatory periodic inspections of diesel vehicles (MEWR, 2009).

To encourage green vehicles, Singapore has introduced a green vehicle rebate (GVR) scheme in 2001 which offers an offset on the registration fees for green vehicles. Recent upgrade of the GVR scheme allows a rebate equivalent to 40% of vehicle's open market value (OMV) for electric, petrol-electric hybrid, CNG, bi-fuel (CNG/petrol) passenger cars, 5% of OMV for buses and commercial vehicles with the same fuel type, and 10% of OMV for electric motorcycles (NEA, 2002). The number of green vehicles increased from a mere 713 in 2006 to 4582 in 2009, of which 30 are buses and 1859 were taxis (LTA, 2010). Both bus and taxi companies are now renewing their fleet with environment friendly and greener vehicles. In 2010, about 10% of taxis in Singapore were running on CNG and this number is expected to increase in near future (C. Melchers, 2010).

3. ROAD SAFETY INITIATIVES

The road traffic crash rate per 100,000 registered vehicles in 2008 was 31.1 and the fatality rate per million population of Singapore was 45.7. The contribution of cars, motorcycles, pedal cycles and goods & other vehicles to total road traffic crashes were respectively about 43.6%, 33.0%, 4.1%, and 19.3% (SPF, 2008). While traffic crashes are low by international standards, road safety remains a concern in this efficiency-conscious nation. Singapore has included world class traffic safety legislations, regulation and monitoring systems into the transport network.

Despite having mandatory helmet laws and day time headlight laws, motorcyclists remain the most vulnerable user groups accounting for about half of road fatalities for many years. To enhance safety of motorcyclists, recent initiatives include paving high-skid resistant materials at crash-prone sites, installing better vehicular impact guardrails appropriate for motorcyclists, and providing more rain shelters along expressways to encourage motorcyclists not to ride in the rain (LTA, 2008a).

Pedestrians are another vulnerable road user group accounting for about 28% of road traffic deaths. Recent engineering solutions to promote pedestrian safety include the installation of intelligent road studs at pedestrian crossings to warn motorists about the presence of pedestrians at night; personal electronic devices for elderly pedestrians to allow more crossing time; and advance road markings, raised zebra crossing, real time speed advisory signs, flashing beacons at zebra crossings, and traffic calming markings to reduce the speed of vehicles at pedestrian crash-prone areas.

The Road Safety Engineering Unit of LTA is responsible to ensure good and sound road engineering practices, enhance road safety, and work with other agencies involved in road safety. Some recent initiatives of this unit include identification and improvement of black spot locations, 'Enhanced School Zone' design to improve traffic safety around schools, installation of crash cushions at high-risk locations to reduce injury severity, installation of real-time speed display signs to encourage motorcyclists to obey the speed limit, installation of advance warning lights to alert motorists about the presence of a traffic signal in case of reduced sight distances due to road geometry, paving traffic calming markings to reduce speed, and installation of Vibralines along the edge of expressways to alert drivers to stay on the main course of the road (OM, 2011).

Figure 4: Some road safety initiatives in Singapore

Since public transport is extensively used, the safety of commuters is enormously important to ensure its reliability. Bus stops and MRT stations are the two key areas of commuters' safety. Bus stops along high speed roads or at road bends are equipped with concrete bollards to protect waiting commuters from runaway vehicles. Safety bollards also alert other drivers about the presence of bus stops, especially during night-time. On the other hand, there have been some recent incidents at elevated MRT stations resulting track intrusions. To reduce such incidents, LTA is planning to install half-height platform screen doors at all above-ground MRT stations by 2012 (LTA, 2008a).

While LTA looks into road safety through various engineering solutions, Singapore Traffic Police is responsible for enforcing traffic laws and regulations on roads and promoting road safety by influencing behavior and skills of road users. Besides strict enforcements of traffic laws, Singapore Traffic Police in collaboration with other agencies develops a myriad of safety campaigns and public education outreach programs every year primarily targeted at vulnerable road users. Some of these include ride safe program, road safety outreach program, the road courtesy campaign, the anti-drink drive campaign, and child seats educational programs (SPF, 2008). Trade associations, non-government organizations, and various private companies also play a vital role in organizing safety campaigns and awareness programs (Chin and Tan, 2003).

Singapore traffic police is also responsible for testing drivers for licensing, while driving centers train the novice drivers and riders through a structured training process. To encourage safe road behaviors, driving schools have developed various comprehensive theory and practical lessons which are also updated and revised regularly. For example, realizing the problem of motorcycle safety on expressways, driving centers have extended their rider training programs to expressways to train motorcyclists about potential hazards at the high speed roadways. Driving centers also use riding and driving simulators to train riders and drivers about potential dangerous encounters on roads which might not be possible to demonstrate in a real world setting.

Road safety education has been included in the curriculum of primary school education by the Ministry of Education (MOE) to raise road safety awareness and encourage good habits an early development stage. The curriculum includes pedestrian safety, cyclist safety, causes of traffic crashes, use of traffic lights, and safety on public transport. In addition to the formal classes, all primary five students are given practical classes by arranging traffic games at Road Safety Park. Furthermore, regular road safety talks are also conducted by schools at assembly talks and exhibitions (Chin and Tan, 2003). MOE works in partnership with traffic and neighborhood police in promoting road safety education at schools as well as in controlling traffic during school events.

4. SMART TECHNOLOGIES

Smart technologies in Singapore's transport system can be broadly categorized into four divisions according to their primary functions: Control systems, Monitoring and enforcement systems, Information management systems, and Revenue management systems. Note that the classification has been done at the city-level. 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. In subsequent sections, key smart technologies in the four divisions are summarized whereas a detailed description of these technologies could be found in Debnath et al. (2011).

4.1 Control Systems

Singapore land transport system has adopted many smart control systems that manage traffic flow efficiently using automated traffic signals like Green Link Determination System (GLIDE), B signal, countdown signal and intelligent road studs (see figure 5). GLIDE is an adaptive traffic signal system that continuously collects traffic data (through detection of vehicles and pedestrians) and automatically allocates signal timing based on traffic volume along each direction of an intersection while allowing signal coordination along a corridor (OM, 2011). Some intersections are also equipped with a transit signal priority scheme (i.e., B-signal) which detects approaching buses and facilitates their movements by extending green time as well as turning on the B-signal to allow an earlier start. Detection technology of some traffic signals enables the recognition of elderly pedestrians via tapping of senior citizen concession cards, and helps to allocate an extended green period for crossing. Some are also equipped with countdown timers and audio signals to aid respectively hear-impaired and vision-impaired people. Another recent improvement is the installation of intelligent road studs at 17 major intersections (OM, 2011) which alert motorists about the presence of pedestrians by blinking the studs on pavement.

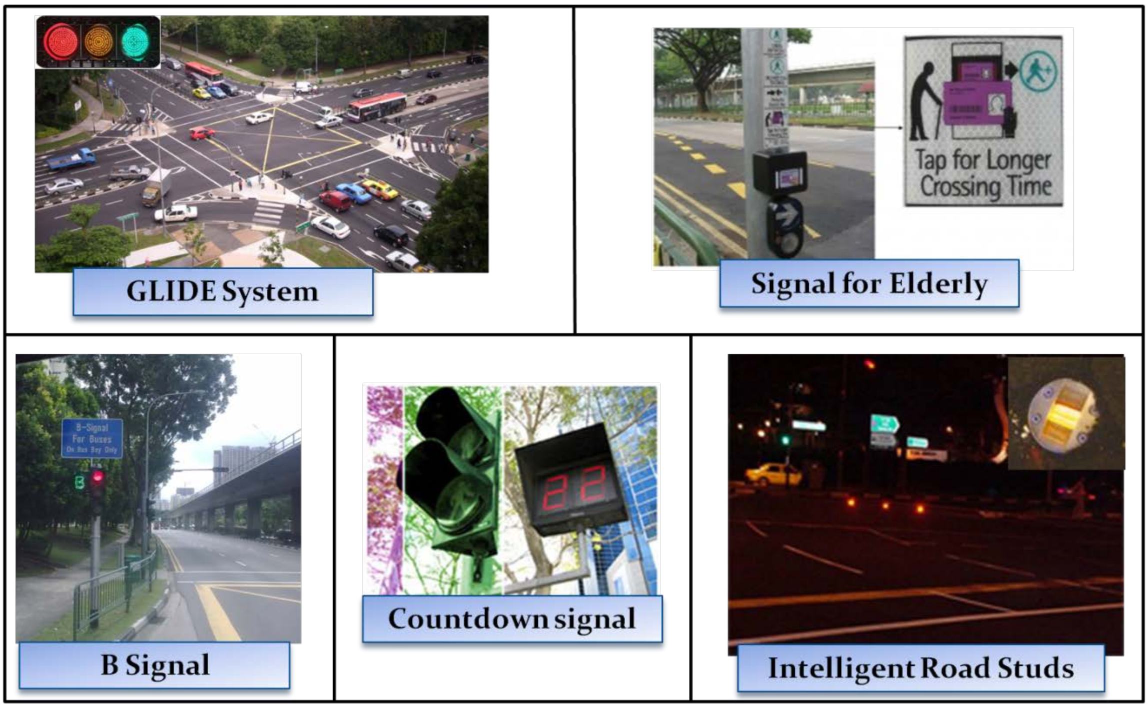

Figure 5: Some implemented smart control systems in Singapore

4.2 Monitoring and Enforcement Systems

Technological advancements allow transport authorities to continuously monitor transport facilities, sense disturbances in traffic flow and identify traffic violations. Singapore has set up an Intelligent Transport Systems (ITS) centre to enhance the efficiency of its land transportation system. It operates 24 hours every day, keeping track of traffic flow based on information gathered by the various ITS on expressways, major arterials and intersections. Some of the monitoring and enforcement systems are shown in figure 6.

To ensure smooth operation and safety, expressways are equipped with a smart incident management system called Expressway Monitoring and Advisory System (EMAS). It automatically detects incidents and congestion and allows authorities to take quick actions like dispatching recovery vehicles and disseminating congestion information. An estimate showed that the cost of time saving due to shorter delays on expressways was about S$40 million per annum (LTA, 2008a). The EMAS service is planned to extend to 10 major arterials over next few years (OM, 2011).

In Singapore, more than 320 major signalized intersections are equipped with advanced surveillance cameras (J-Eyes) to help detection of irregular traffic situations including congestion, illegal parking and loading/unloading (OM, 2011). J-Eyes are operated by the ITS centre, where the Operations Executives can monitor traffic closely and implement appropriate actions. To deter risky driving on roads, Singapore Traffic Police has installed speed cameras at 45 locations and red light cameras at most major intersections. These cameras automatically detect respectively speeding and red light running vehicles, and take snapshots of the registration plates for identification.

To ensure a smooth operation of Bus lanes, LTA utilizes a smart bus lane enforcement system, whereby cameras are installed on-board of the buses to detect bus lane infringements.

A total of 90 buses of 12 routes were fitted with the cameras in 2008 (OM, 2011). This system requires a little intervention by the bus driver as the video camera is set to continuously monitor the road in front of the bus so that infringing vehicles can be identified accurately.

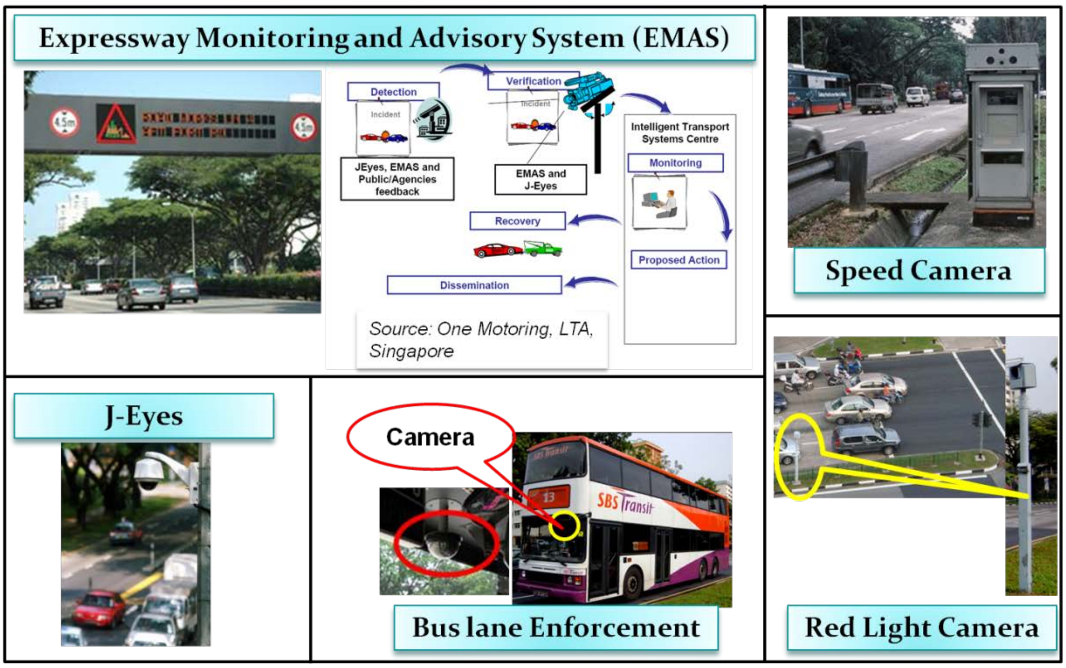

Figure 6: Monitoring and Enforcement systems in Singapore

4.3 Information Management Systems

Information management systems collect, process, and share real-time traffic information with travelers via fixed and mobile platforms, so that they can plan (and modify) their routes in advance. Figure 7 represents some of the information management systems deployed in Singapore. Smart information management systems can be divided into two categories: traffic news broadcasting and public transport information sharing.

4.3.1 Traffic News Broadcasting

The smart system TrafficScan uses data from taxis equipped with GPS to provide average travel times along roads. Incidents and congestion information from EMAS and J-Eyes are provided to travelers through LTA portals, in-vehicle devices (e.g., radio), navigational devices, smart phone and variable message signs. To further improve the quality of the traffic advisory information, a smart traffic prediction tool is being developed that will use advance statistical techniques to predict traffic flow and speed. Currently, LTA is planning to launch a Traffic Message Channel (TMC) designed for delivering real-time traffic and travel information to motorists on the move. TMC will be particularly beneficial to commercial service providers for broadcasting real-time traffic messages to their drivers. The traffic information received can be displayed as text messages on a LCD display of the radio or as graphics on navigation maps of TMC compatible devices such as portable navigation devices (PNDs), in-vehicle navigation systems and mobile phones (OM, 2011). Reliable traffic information systems help transport authorities to divert traffic from congested roads to those less congested, thus increasing system efficiency.

For a better parking management in the CBD, several important locations have been equipped with a smart parking guidance system (PGS) that collects data from various car parks, processes information in a central computer, and displays real-time information on availability of parking spaces. Currently, there are about 25 electronic information display panels positioned at key locations for informing motorists about the number of available parking spaces at the various establishments (OM, 2011). PGS is useful to reduce the amount of circulating traffic searching for available parking facilities in the CBD.

4.3.2 Public Transportation Information Sharing

Four attractive features of this system are: an integrated public transport map, a public transport travel advisor, on-board information services, and an advance taxi booking system. The online integrated map equipped with a web-based multi-modal journey planner allows travelers to plan routes by various transport modes including transit alternatives (rail and bus). The public transport travel advisor improves the convenience of public transport users mainly by providing arrival timings of buses and trains. Bus arrival timings are available through internet, smart-mobile applications, and at bus stops equipped with electronic display panels (currently 76 bus stops). For MRT, arrival timings are provided in close proximity of MRT stations and platforms. On-board real-time information on next stops and routes are also provided on trains and buses. For taxis, service providers use a smart taxi booking system which allows passengers to book a taxi using the internet, smart-mobile applications, SMS, or phone. Contact centers wirelessly connect to taxis using General Packet Radio Service technology and in-vehicle mobile data terminals to process booking requests. To further improve the service, a common telephone number has been introduced recently to remove the ambiguity of using different numbers for different taxi service providers (LTA, 2008b).

Figure 7: Information management systems in Singapore

4.3.3 Other Initiatives
Apart from the above initiatives, Singapore is anticipating the use of next-generation electronic road pricing system (ERP II) with GPS or GNSS technology which will also be helpful for an enhanced data collection and dissemination of traffic information (LTA, 2008a). This might be helpful to make better journey plans, enable dynamic fleet management of logistics and taxi companies, give priority to emergency vehicles, increase smart safety applications and relieve congestions.

4.4 Revenue Management Systems

Managing fast and accurate transactions of public transport fares and automobile toll payments is important for a transport system to be efficient. Singapore is utilizing various smart technologies for a better management of revenue systems to collect public transport fares, parking charges, and tolls (see figure 8). The contactless tap-and-go fare card for public transport (i.e., EZ-link card) allows paying fares on all transport modes including MRT, LRT and buses. The recent upgrade of that smart card - the Symphony for e-Payment (SeP) - now facilitates payments of other usages like ERP charges, parking fees, and expenses at many retail outlets. As discussed in section 2.3.2, the ERP is a smart technology that automatically collects tolls via gantries and in-vehicle units during real-time traffic operations. The next generation of this system (ERP II) via GPS or GNSS technology will no longer required physical gantries and will implement a fairer congestion charge based on the actual distance traversed. Fare collections of taxis have also been upgraded to incorporate cashless payments. Fares on most of the taxis can now be paid on-board using local bank cards or international credit cards.

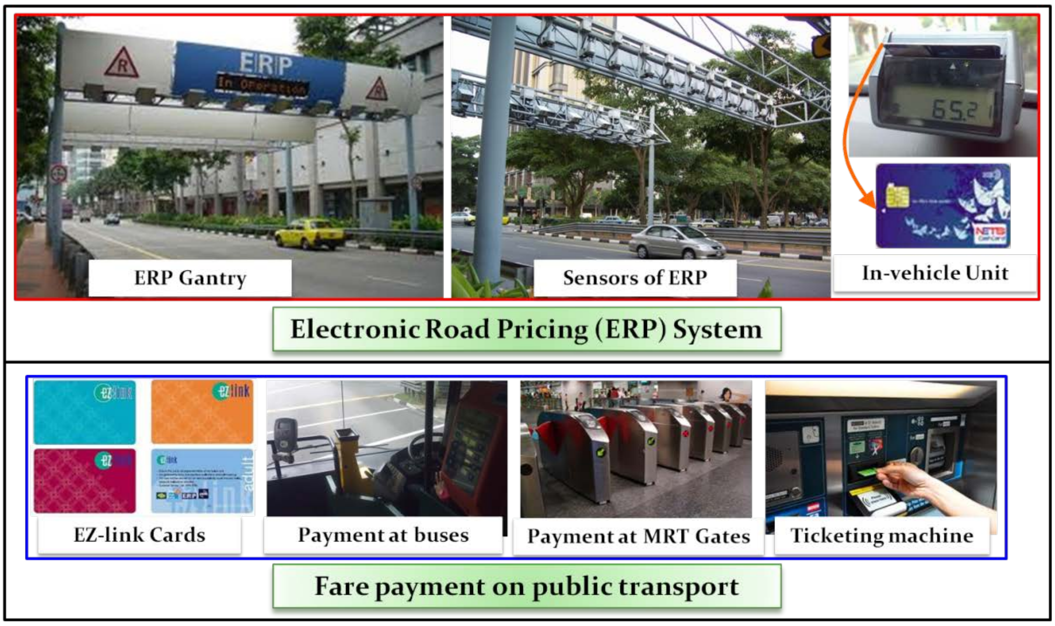

Figure 8: Revenue management systems in Singapore

5. DISCUSSIONS

In light of the policy implications along sustainability, safety and smartness, this section describes some inherent strategies learnt from the Singapore experience, identifies some limitations on the adopted policies, and recommends some suggestions for the development of a better urban mobility system.

5.1 Sustainability

Analyzing the policies related to sustainability identifies three main inherent strategies that have helped Singapore to maintain an excellent transportation system over the years. These include: 1) proper balance between transport supply and demand, 2) competitions among public transport operators, and 3) pragmatic approach of planning.

Proper Balance between Transport Supply and Demand: An important learning is that there must be a proper balance between transport demand management and transportation supply measures in order to achieve sustainability particularly without compromising economic developments. As seen from the transportation system of Singapore, the growth and usage of private motorization has been controlled by various policies like vehicle quota system (VQS) and congestion charging scheme. To meet the travel demand, travelers have been served by a reliable and convenient public transportation system instead. The usage of public transport has been facilitated by providing an integrated public transport network, ensuring a favorable environment on walkways and supporting other facilities like park-and-ride schemes. To further promote the usage, various smart applications in the form of trip planning, bus/train arrival information, smart card fare payment and mobile-based applications have been embedded into the transportation system. Moreover, taxis and other premium services have also been promoted in harmony to offer a luxurious travel choice for user groups who can afford.

Competitions among Public Transport Operators: As learnt from the Singapore experience, maintaining service standards of public transport is an important step to keep people interested on using this mode and to ensure better utilization. The Public Transport Council and LTA set and maintain the service standards through strict regulations. Besides these, a key strategy to maintain a good quality of service was encouraging competitions among public transport operators. The current public transport industry comprises two 'multi-modal' operators: one which mainly operates the RTS as well as a small bus network, and another which mainly operates the buses as well as single RTS line. This multi-modal framework offers the benefits of competition in terms of peer benchmarking in service standards and cost efficiency and avoidance of regulatory capture. The point is not so much the number of operators but the creation of a contestable industry where the threat of loss is real to the incumbents, encouraging them to provide more efficient services. LTA is currently looking forward to increase the number of basic bus operators for a greater competition to further improve the efficiency of bus operations and service standards. Similarly, RTS operators will be offered operating licenses for a shorter period than current 30-year period so that the standards can be improved either by replacing incumbent operators or imposing new regulatory standards (LTA, 2008a).

Pragmatic Approach of Planning: Maintaining an intergeneration equity is the central element of a sustainable transportation system. This has been addressed by a pragmatic approach of planning in the land transport development of Singapore. In 2008, individuals aged 65 and above accounted for about 8.7% of resident population in Singapore (Department of Statistics, 2009). This group of population will be raised up to 20% by 2020. To meet this challenge, land transportation system is continuously implementing policies and strategies to provide travel access to the elderly and physically challenged people. These include priority seats on buses and trains, highly visible traffic signs and barrier free footpaths and public roads for wheel-chair users. It has also been aimed that all buses and trains including bus stops and MRT stations will be wheel-chair accessible by 2020.

Although Singapore has adopted a number of good policies to achieve sustainability, there remain few issues that could be addressed for improvement. These issues include: 1) travel demand during peak hours, 2) accessibility and affordability of public transport, 3) non-motorized transport facilities, and 4) promoting green vehicles.

Travel Demand during Peak Hours: Despite a good public transport system, accommodating peak hour travel demands still remains a concern. Although the average maximum passenger loading on the MRT is low (3.7 persons per square meter) by international standards, trains and MRT stations are usually very crowded during peak hours. Authorities should look forward to improve MRT capacities by providing more frequent trains and increasing the MRT network. In addition to the crowd during peak hours, boarding on buses takes a lot of time due to on-board tapping of fare cards and single-door entries. Implementation of off-board fare collection system and multi-door entries on buses may be a suitable alternative to decrease this time wastage. Besides these, bus operators have difficulties in meeting operating standards regarding headway adherence particularly during peak hours. It was reported that about 65% of bus routes failed to operate buses by maintaining headways less than 10 minutes (LTA, 2008a). To overcome this, PTC has imposed a more stringent standard requiring 90% buses should have headways less than 10 minutes during weekday peak period, compared to the earlier standard of 85%. However, to achieve a greater performance, bus fleet should be increased and service standards should be monitored and enforced regularly.

Accessibility and Affordability of Public Transport: Accessibility and affordability of public transport for the poor is an important intra-generation equity issue of a sustainable transportation system. Cho-yam Lau (2011) argued that despite Singapore’s world-class public transport system, most poor workers could not afford to take the MRT to reach their jobs. It was demonstrated that poor workers tended to take buses for long haul travel to work instead of hub-and-spoke network mainly because of higher fares. As a result, they had to spend a longer time for the work trip. To ensure an affordable public transport mode to low income groups, the government is currently targeting to help the needy through various forms of assistance such as Workfare Income Supplement (WIS) scheme and community help schemes such as transport vouchers (LTA, 2008a). However, specific supplementary measures in terms concessions could be offered to encourage these workers to use hub-and-spoke network instead of buses.

Critique also claims that Singapore has a spatial mismatch between jobs and residential areas because most jobs are located at the central area (Cho-yam Lau, 2011). To reduce the heavy loads on the city center, the government developed four regional centers which were expected to have developments with total gross floor areas of 1.5 million meters square serving about 800,000 people each (Chin, 1998). However, regional centers had not been found to be very effective due to the strong city center where most of the investors interested to locate their firms (URA, 2008). A follow up study (Sim et al., 2001) on one of the regional centers reported that total commercial areas on that center was only 0.24 million square meters despite being served by MRT stations and a large bus interchange. Developing better strategies to promote these commercial regional centers could be useful to reduce the number of commuters towards the city centre.

*Non-motorized Transport Facilities: N*on-motorized forms of transport such as cycling have not been found to be properly considered on the land transport development of Singapore. A caveat for cycling is the limited land area that does not allow building cycling tracks over the island. However, an increasing amount of attention is being directed to it as it is recognized to be a green form of commute that promotes an active lifestyle too. More research can be done in this area to find innovative ways to better incorporate cycling into the transportation system, including using it as a link to major public transport nodes. Another non-motorized form of commute is walking, and currently, more seamless ways of connecting pedestrians to transport nodes are being developed. Since Singapore has a tropical rainforest climate condition, walkways should be fitted with shelters to promote walking and facilitate usage of public transports during adverse weather condition.

Promoting Green Vehicles: It has been observed that restriction on vehicle ownership and imposing road pricing are some viable schemes to promote sustainability. However, a complete restriction on private transports can never be achieved. Hence, promoting green vehicles through various policies and government incentives may encourage more motorists towards sustainability. Moreover, bus and taxi companies should put more efforts to promote environment-friendly vehicles in their fleet.

5.2 Safety

It is evident that Singapore has a very good safety standard for various road user groups. However, traffic safety still remains a concern for vulnerable road users like motorcyclists and pedestrians contributing to respectively about 49% and 28% of road traffic fatalities (SPF, 2008). Haque (2011) has reported that the fatality and injury rates of motorcyclists are respectively 19 and 7 times higher than any other motor vehicle occupants. Crash statistics on pedestrians show that more than a pedestrian is killed in a motor vehicle crash every week and about three pedestrians are injured every day (Haque, 2011). Although some initiatives (see section 2) have been taken to encounter safety problems of these vulnerable road user groups, it appears that they are not sufficient. More innovative research should be conducted to investigate the root causes and develop targeted countermeasures.

Singapore Traffic Police in conjunction with various stakeholders is continuously arranging many road safety campaigns with the sole intention to increase the safety awareness of various road users. These safety campaigns and public education programs could be more utilized if proper safety messages could be delivered to the target group. For example, several studies (e.g., Haque et al., 2012) have reported that the likelihood of motorcycle crashes in Singapore is consistently higher during night due to poor conspicuity of motorcyclists. Recognizing this fact, a safety campaign on motorcyclists could encourage riders to wear reflective clothes during night.

Overall, to further raise the road safety standards of Singapore, there has to be a change in mind-set of all road users such that individuals understand and undertake their own social responsibility toward safety, and begin to act more safely on roads. To achieve a higher level of safety awareness, authorities should be more conscientious in promoting and enforcing road safety. Moreover, there must be greater coordination and dialogue among the different road safety stakeholders.

5.3 Smart Technologies to Promote Sustainability and Safety

The Singapore experience shows that smart technologies help to implement or escalate various policies and strategies related to sustainability. For example, smart technologies like bus priority signal system, bus lane enforcement system, availability of real-time service information and an integrated multi-modal fare payment technology have been helpful to promote public transport as a viable alternative to private transport. Traffic signal coordination system using GLIDE helps to ensure a smooth flow along the corridor and hence reduces congestion, fuel consumption, and emissions. Smart taxi booking system and public transport information sharing system have increased the accessibility of commuters. In addition, availability of real time traffic and travel related information have enhanced motorists' flexibility in route planning for a less congested, faster and safer trip. The electronic toll payment system is another smart technology which has been successfully implemented to facilitate the road pricing policy for managing congestion and hence promoting sustainability.

In similar ways, various smart technologies assist improving safety of various road users. A technology like elderly pedestrian signal allows an extended green time for elderly to cross the road comfortably and enhances safety. Intelligent road studs warn motorists about the presence of pedestrians on a pedestrian crossing at intersections and help to improve their safety particularly during night. Similarly, countdown timers and audio signals enhance safety for physically challenged people like hear-impaired and vision-impaired. Speed cameras and red light cameras assist automated law enforcements on crash prone areas. A real time smart incident detection system, EMAS facilitates dispatching emergency vehicles to the injured quickly and minimizes the loss of life by providing fast medical services.

Despite having many advanced smart technologies in place, capabilities of these technologies have not been exploited efficiently. For example, all the individual vehicles in Singapore are detectable by in-vehicle unit (IU) mainly to facilitate electronic road pricing, however the use of IU has not been extended in other areas like traffic flow management and safety improvement. Instead of current loop detection at a signalized intersection, IU could be used to detect an oncoming bus early and a B-signal could be assigned accordingly. Detection of vehicles at blind spot locations could be explicitly used for crash avoidance by conveying this message to other drivers by an electronic message sign or in-vehicle devices. On the other hand, smart card payments of public transport fare provide an intensive real time travel demand data but have not been utilized efficiently. Transport authority could explicitly use this data for dispatching buses or trains according to the travel demand and hence might be useful to utilize the public transport more efficiently.

6. CONCLUSION

This paper studies evolving transport policies and strategies of Singapore and reveals that there are three unique elements inside its transportation system namely sustainability, safety, and smartness. Policy directions along these three components helped Singapore to develop a viable and efficient urban mobility system. The Singapore experience shows that promoting public transport as a viable alternative to private transport may be the best way to achieve sustainability with targets of reducing traffic flow, congestion, fuel consumptions, and emissions. In general smart technologies facilitate implementation of different policies and strategies of sustainability like promoting public transport, increasing commuters' comfort, minimizing congestion, and reducing environmental emissions. Smart technologies also help to enhance safety in various ways like accelerating the incident management, imposing restrictions on risky drivers, and introducing additional safety measures for vulnerable road user groups like elderly and physically challenged. The development and inclusion of newer and smarter technologies with enhanced abilities will make the transportation network more efficient and solve many transport problems. The success of Singapore's policy implications for its transport system may serve as a good reference for other cities in developing sustainable, smart, and safe modern transportation system.

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