SUSTAINABLE, SMART, SAFE - A 3'S' APPROACH TOWARDS A MODERN TRANSPORTATION SYSTEM

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Abstract: Sustainability, smartness and safety are three sole components of a modern transportation system. The objective of this study is to introduce a modern transportation system in the light of a 3'S' approach: sustainable, smart and safe. In particular this paper studies the transportation system of Singapore to address how this system is progressing in this three-pronged approach towards a modern transportation system. While sustainability targets environmental justice and social equity without compromising economical efficiency, smartness incorporates qualities like automated sensing, processing and decision making, and action-taking into the transportation system. Since a system cannot be viable without being safe, the safety of the modern transportation system aims minimizing crash risks of all users including motorists, motorcyclists, pedestrians, and bicyclists. Various policy implications and technology applications inside the transportation system of Singapore are discussed to illustrate a modern transportation system within the framework of the 3'S' model.

Key Words: *Sustainability, Smart, Safety, Transportation System, Singapore*

1. Introduction

Now-a-days the development of a sustainable transportation system is a global issue mainly because of an increasing concern on environment issues. At the same time, recent technological revolutions 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. In addition to sustainability and smartness, safety should not be ignored to have the system feasible. Hence a modern transportation system should promote social and economic welfare in a safe and efficient way without damaging the environment or depleting environmental resources. The concept of this novel approach along with major components is shown in Figure 1.

A sustainable transport system has three major targets: 1) economic development, 2) environmental issues, and 3) social equity. In light of this, it has been defined [1] 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.

Recent advancements in technological developments have made urban transportation systems more efficient through the use of smart technologies. 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 [2]. Having sensing ability, a smart technology able to process and interpret the received information and capable to execute decisions into actions through actuators. These activities follow a cyclical pattern and make a smart technology forming a closed-loop monitoring and action-taking process.

In the transport system, safety is a significant component that ensures viability. Road safety is an important public health issue and traffic incidents are not only costly for the injured, but a burden on society and national health systems. Since a transportation system is dynamic and has a human component, incidents are an inevitable consequence. Hence a transport system targets to minimize the injuries and casualties of its users, promotes safe road usages through the development of proper

infrastructures and environment, and encourages safe road behaviours through education and legislations.

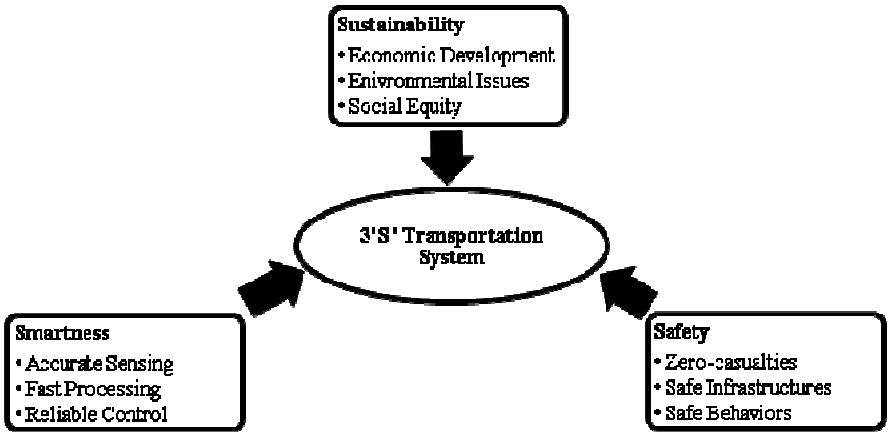

Figure 1: *Framework of a 3'S' Transportation System*

In light of the above, it appears that sustainability, smartness, and safety are three important components (3'S') of a modern transportation system. The objective of this study is to illustrate how the transportation system of Singapore is progress towards this three pronged approach. In subsequent sections, this paper discusses important steps and initiatives of the transportation system of Singapore to achieve sustainability, smartness, and safety. Lastly, the paper discusses some concerns and future aspects in development of a modern transportation system.

2. Sustainable Transport Planning in Singapore

Over the years, various strategies and policies have been implemented into the transport system of Singapore on its path towards sustainable development. The sustainability issues from the experience of land transport development of Singapore can be broadly categorized into four key areas: 1) integration in land use and transport planning, 2) transport supply measures, 3) transport demand management, and 4) incorporation of environmentally-friendly technologies for vehicles.

2.1 Integration in 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 those were required. The first strategic development plan in 1971 decentralized population by developing residential blocks further away from CBD and connected by roads, expressways, and MRT (Mass Rapid Transit) lines. Later, the revised concept plan of 1991 [3] aimed to further decentralize commercial and economic activities by developing regional and sub-regional centres around MRT stations. The locating of employment centres, industrial estates, business parks, and commercial centres near residential areas reduced the people's need for travel, while resulting in a better utilization of the MRT network. For a better integration, a hierarchical system with well-defined roles for each transport mode was also designed. While railways serve the long-haul travel, LRT (Light Rapid Transit) and buses provide services feeder services to connect areas in housing states to MRT stations. Those strategic plans not only restricted the development of urban sprawl but also reduced the number and length of trips of commuters and hence were the key steps towards sustainability.

2.2 Transport supply measures

The increase in population and economic activities will increase the daily travel demand from the current 8.9 million to about 14.3 million journeys by the year 2020. To meet the mobility needs of people in a sustainable way, transport authorities are planning to double the public transport trips (about 10 million) by 2020. Therefore, recent transport supply measures on land transport master plan *(4)* mainly focus on initiatives promoting public transports including rapid transit system, buses and taxis.

Rapid Transit System (RTS): RTS network in Singapore consists of MRT and LRT. The current 148 km long RTS network consists of four MRT lines (68 stations), three LRT lines (33 stations) that accommodate a total about 1.7 million passenger trips daily [5]. Ibrahim [6] has reported that more than 60% of Singaporeans use the MRT for commuting and other trips. To accommodate the projected demand, the MRT network has been planned to be doubled to 278 km by 2020 including two new lines and extensions on existing lines that will lead to a total 36 new stations.

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 [5]. Recent policies to improve and promote bus services include peak hour bus lanes, full day bus lanes, priority at signalized junctions, and mandatory give way to exiting buses from bus bays. A 120 km of peak hour bus lanes and 7.6 km of full day bus lanes has improved the bus speed by about 16%. 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. Those include premium bus services, express bus services, intra town services, night bus services, and niche public bus services.

Integrated rail and bus services: To make journeys more seamless and convenient for commuters, there has been a deliberate move towards integrating rail and bus services through coordinating network, physical facilities, fares, and information. Bus stations are strategically located near MRT stations and connected with well designed walkways for the convenience of commuters. A common ticketing system in the form of a universal fare card ("EZ-link") was developed for use on both trains and buses. To further improve transfers by removing the current fare penalty, a distance-based through fare structure has been implemented recently. The integrated information system for public transport will be discussed in section 3.3.

Taxis: Taxis bridge the gap between basic public transport modes and private cars, by offering commuters the choice to have personalised high-end door-to-door service. There are currently 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 companies, quality standards are regulated and enforced by the Land Transport Authority (LTA).

Other facilities to improve the usage of public transport: The 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. Singapore has currently 40 major public transport nodes with park and ride sites (about 5000 parking lots) where motorists can park their vehicles and take public transport to travel to the CBD. Similarly most of the MRT stations and bus interchanges have bicycle parking facilities that encourage commuters to cycle from the housing estates to public transport nodes. MRT and buses now also allow foldable cycles on board to further promote this environment-friendly mode.

Meeting diverse needs of people: Equity is a key component of a sustainable transport system which must be ensured by providing transportation needs for various user groups including elderly and physically challenged people. For this group 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 accesses by 2020. Recent initiative to improve the walkways for elderly and physically challenged people include installation of tactile guidelines, at-grade pedestrian crossings, thickened road crossing lines for vision impaired, and audio-alert crossing facilities for hearing impaired.

2.2 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 growth of motorization and imposing road pricing policies.

Controlling growth of motorization: Singapore maintains a sustainable rate of growth (about 3% p.a.) of its vehicle population by 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. Recently the vehicle growth rate is set to 1.5% p.a. to ensure long term sustainability [4]. In light of high costs of cars due to the VQS,

the off-peak car scheme (OPC) allows people to buy cars at a cheaper rate but restrict the usage of cars from 7:00 am to 7:00 pm on weekdays. OPCs currently make up about 8% of the total car population.

Imposing road pricing: In addition to purchase-based constraints, road pricing is a usage-based tax system discouraging use of expressways and main roads towards CBD during peak hours to prevent congestion. Congestion prices are collected by an electronic road pricing (ERP) system that functions with gantries on roads and in-vehicle units at vehicles and capable to collect chargers at operating speed. Through regular reviews and rate adjustments, traffic on priced roads is relatively smooth-flowing as such charges divert traffic from busy roads. ERP has been effective in maintaining an optimal speed range of 45 to 65 km/h for expressways and 20 to 30 km/h for arterial roads. The technology for road pricing will soon be updated ("ERP II") with the incorporation of Global Positioning System (GPS) technology that enables distance-based congestion charging without the need for physical gantries. It will be a more flexible and efficient method of managing congestion, and thus more effective and sustainable in the long run.

2.4 Incorporation of environment-friendly technologies and policies

To address environmental sustainability, green technologies and policies are also incorporated to promote green vehicles. This is done by raising emission standards for vehicles and encouraging the use of cleaner fuels and more energy efficient vehicles.

Through strict emission regulations, Singapore's ambient concentration of most air pollutants has stayed within international standards except for particulate matters smaller than 2.5 microns in size (PM2.5). To restrict those particles, more stringent emission standards (Euro IV) have been planned to be implemented for all vehicles by 2020 leading about 70% less PM2.5 than current time [4]. Another policy to control emissions is that vehicles older than 10 years are subjected to a surcharge tax on their annual road taxes.

To encourage green vehicles, Singapore has introduced green vehicle rebate scheme which offers an offset on their registration fee of about 40% and 10% of open market values respectively for cars and motorcycles. Both bus and taxi companies are now renewing their fleet with more environment friendly and greener vehicles. The number of green vehicles in total has increased from a mere 713 in 2006 to 4582 in 2009, of which 30 are buses and 1859 are taxis [7]. Currently one Taxi Company is operating 1000 taxis on CNG and intends to bring another 3000 within next two years.

3. Smart Technologies in Singapore

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 in 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.

3.1 Control Systems

Smart control systems manage traffic flow efficiently using automated traffic signals. An adaptive traffic signal system (i.e., GLIDE) continuously collects traffic information (through detection of vehicles and pedestrians) and automatically allocates signal timing at intersections, while allowing signal coordination along a corridor. 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 for an earlier start. Detection technology of some traffic signals enables the recognition of elderly pedestrians via the tapping of senior citizen concession cards, and increases their green time. Some are also equipped with countdown timers and audio signals to aid the disabled. Another recent improvement is the installation of intelligent road studs at 17 major intersections [8] which alert motorists to the presence of pedestrians crossing by blinking on the pavement.

3.2 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 speed cameras at 45

locations and red light cameras at most major intersections. They automatically detect respectively speeding and red light running vehicles, and take snapshots of the registration plates for identification. For smooth operation and safety, expressways are equipped with Expressway Monitoring and Advisory System (EMAS), which is a smart incident management system. It automatically detects incidents and congestion, allowing authorities to take quick action (e.g. dispatching recovery vehicles and disseminating congestion information). The service is planned to extend to 10 major arterials by 2013 [8]. Outside of expressways, about 280 advanced surveillance cameras (J-Eyes) operate at major signalized intersections [8] to help traffic control centre operators detect irregular traffic situations, including congestion, illegal parking and loading/unloading. To regulate Bus lane and Mandatory give-way to buses policies [4], LTA utilizes a smart bus lane enforcement system, whereby cameras are installed on-board the buses to detect violations of the bus lanes. A total of 90 buses of 12 routes were fitted with the cameras in 2008 [8].

3.3 Information Management Systems

Information management systems collect, process, and share real-time traffic information with travellers via fixed and mobile platforms, so that they can plan (and modify) their routes in advance. Smart information management systems can be categorized into two: traffic news broadcasting and public transport information sharing.

Traffic News Broadcasting: The smart system TrafficScan uses data from taxis that equipped with GPS to provide average travel time along roads, while incidents and congestion information from EMAS and J-Eyes is provided to travellers through LTA portals, in-vehicle devices (e.g., radio) and variable message signs. To further improve, a smart traffic prediction tool is being developed for better traffic advisory information that will use advanced statistical techniques for predictions. Other than those, the smart parking guidance system in CBD collects and processes information in a central computer and displays real-time information on available parking spaces through 24 electronic panels [8].

Public Transportation Information Sharing: The 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 provides travellers with transit alternatives (rail and bus) and a web-based multi-modal journey planner determining the best routes for travellers. The public transport travel advisor facilitates the convenience of travel by mainly providing arrival timings. Bus arrival timings are available through internet, SMS (currently 215 stops), and at bus stops equipped with electronic display panels (currently 76 bus stops). For MRT, arrival timings of trains are provided in the 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, where passengers can book using the internet, SMS, or phone. Contact centres wirelessly connect taxis using General Packet Radio Service technology and in-vehicle mobile data terminals to process the booking requests. To further improve the service, recently a common telephone number for all taxi services has been introduced [9].

Apart from the above initiatives, Singapore is anticipating the use of next-generation electronic road pricing system (ERP II) with GPS technology which will also be helpful for the enhanced collection and dissemination of traffic information [4]. That information will help to make a better journey plans, enable dynamic fleet management of logistics and taxi companies, give priority to emergency vehicles, and relieve congestion.

3.4 Revenue Management Systems

Managing fast and accurate transactions for public transport fare and toll payments is important for a transport system to be efficient. Singapore has been utilizing smart technologies for better management of revenue systems, such as public transportation fare payment, parking charge payment, and toll collection. The contactless tap-and-go fare card for public transport (i.e. EZ-link card) allows for paying of fares in all transport modes including MRT, LRT and buses. The recent upgrade of that smart card - the Symphony for e-Payment (SeP) - now includes payment for other usages like ERP, parking, and many retail outlets. As discussed in the previous section, the ERP is also a smart technology that automatically collects tolls via gantries during real-time traffic operations. The next generation of this system (ERP II) will remove physical gantries and implement a distance-based congestion charging via GPS technology.

4. 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 43.6%, 33.0%, 4.1%, and 19.3% [10]. While traffic crashes are low by international standards, road safety remains a concern in the efficiency-conscious nation. Singapore has included world class traffic safety legislations, regulating and monitoring systems into the transport network.

Despite of mandatory helmet laws and day time headlight laws, motorcyclists are 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 to encourage motorcyclists not to ride in the rain [4].

Pedestrians are another vulnerable road user groups 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; personal electronic devices for elderly pedestrians to allow more crossing time; and advance road markings, real time speed advisory signs, 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. 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, erecting concrete bollards at selected bus stops to protect waiting commuters from runaway vehicles, and installation of Platform Screen Doors at MRT stations above the ground to promote safety of commuters [4, 8].

While LTA looks into road safety through various engineering solutions, the Traffic Police is responsible for enforcing traffic laws and regulations on roads and promoting road safety by influencing behaviour and skills of road users. Besides enforcements, various education and safety campaigns have also been organized by the Traffic Police. Every year, the Singapore Traffic Police in collaboration with other agencies develop a myriad of public education outreach programmes primarily targeted at vulnerable road users. Some of these include safety education of primary school children couple with traffic games at Road Safety Park, ride safe programme, the road courtesy campaign, the anti-drink drive campaign and other educational programmes to encourage the proper use of child seats. Trade associations, non-government organizations, and various private companies also play a vital role in organizing safety campaign and awareness programmes [11].

5. Discussions

Achieving sustainability is very challenging for a transportation system. Singapore experience shows that promoting public transport may be best way to achieve sustainability. However it is still very challenging to accommodate future travel demand within the public transport. Although the average maximum passenger loading on the trains is low (3.7 persons per square metre) by international standards, MRT are very crowded during the peak hours. Authorities should look forward to improve this condition. For buses, in addition to the crowd, boarding on buses still takes a lot of time due to on-board tapping of smart cards. Implementation of off-board fare collection system may be a suitable alternative to decrease this time wastage.

Other than public transport, non-motorised forms of transport such as cycling should also be promoted. 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 transport system, including using it as a link to major public transport nodes. Another non-motorised 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.

It has been observed that restriction on vehicle ownership and imposing road pricing are some viable schemes to promote sustainability. However 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.

With regard to safety, road traffic safety is still remaining a concern. A scientific estimate [12] put the total cost of road traffic crashes in Singapore at about S$610.3 million for the year 2003 which was about 0.3% of the annual GDP. In particular, motorcyclists and elderly pedestrians should be targeted for safety improvements. More innovative researches should be conducted to investigate the root causes and countermeasures for those problems. Overall, to further raise the road safety standards of Singapore, there has to be a change in mind-set for 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.

In general smart technologies facilitate implementation of different policies promoting a sustainable and safe transport system. For example, to promote public transport as a viable alternative to private transport, many smart technologies have been implemented such as the bus priority signal system, bus lane enforcement system, availability of real-time service information and an integrated multi-modal fare payment technology. Availability of traffic and travel related information also has the potential for enhancing motorists' flexibility in route planning so as to ensure a less congested, faster and safer trip. To enhance safety of motorists and pedestrians at intersections, a set of smart traffic control systems is also used which increases efficiency of road networks and environmental health. The electronic toll payment system is another smart technology which has been successfully implemented to facilitate the road pricing policy for managing congestion and hence promoting sustainability. The development and inclusion of newer and smarter technologies with enhanced abilities will make the transportation network more efficient and solve many transport problems.

6. Conclusion

A 3'S' approach is highly desirable for a modern transportation system to be viable and efficient. Sustainability, smartness, and safety are three major components to enhance mobility and accessibility, ensure safety and social equity, improve system efficiency, protect the environment and importantly foster the economy. As learnt from the Singapore experience, sustainability, smartness and safety are not only the three most critical components of a modern transportation system, but are actually closely related to each other too. To develop a sustainable and safe transport system, smart technologies should also be incorporated to increase efficiency and reliability. The success of Singapore's 3'S' approach for its transport system may serve as a good reference for other cities in creating sustainable, smart, and safe modern transportation system.

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