POTENTIAL APPLICATIONS OF INTELLIGENT TRANSPORTATION SYSTEMS IN SINGAPORE

Ruey-Long CHEU
Lecturer
Department of Civil Engineering
The National University of Singapore
10 Kent Ridge Crescent
Singapore 0511, Singapore
fax:(65)779-1635

abstract: Singapore is well known for its land transportation policies. Although the nation is not in the forefront of Intelligent Transportation Systems (ITS) research, several aspects of it will be implemented in the next few years. The electronic road pricing system will be operational in 1997. Bus and taxi companies will also have their vehicle tracking systems. This paper describes the proposed systems and their possible expansion in the context of advanced traffic management systems (ATMS), advanced traveller information systems (ATIS) and advanced public transportation systems (APTS). The potential advantages and problems in integrating the different components will also be discussed.

1. INTRODUCTION

Singapore is a city state with land area of 641 km^2 and population of approximately 2.8 millions. The land transportation infrastructure is well developed, with 3000 km of public roads, of which the 120 km expressway system is shown in Figure 1. At the end of 1993, there were 584,000 registered vehicles. The Mass Rapid Transit (MRT) system has 67 km of track and 42 stations in operation (see Figure 1). It enjoys a ridership of 6.5 to 7 million trips per day. Most areas in the island are also accessible via public buses, with two major bus companies providing 240 services. The country is noted for its successful implementation of innovative transportation policies. It is the first city to implement the area license scheme (ALS), and will be among the first to have an electronic road pricing (ERP) system in operation. In addition to heavy road tax and registration fees, the Government of Singapore instituted a vehicle quota system that controls the vehicle growth rate to 3% per annum. Despite all the policies to curb ownership and usage of private vehicles to reduce traffic congestion, increasing affluence and expectation for higher mobility has exerted pressure on the government to permit a higher car population. With the lack of space to build new transportation facilities, the intelligent transportation systems (ITS) offers a new alternative to increase the carrying capacity of existing road network, and make public transportation more attractive to the population.

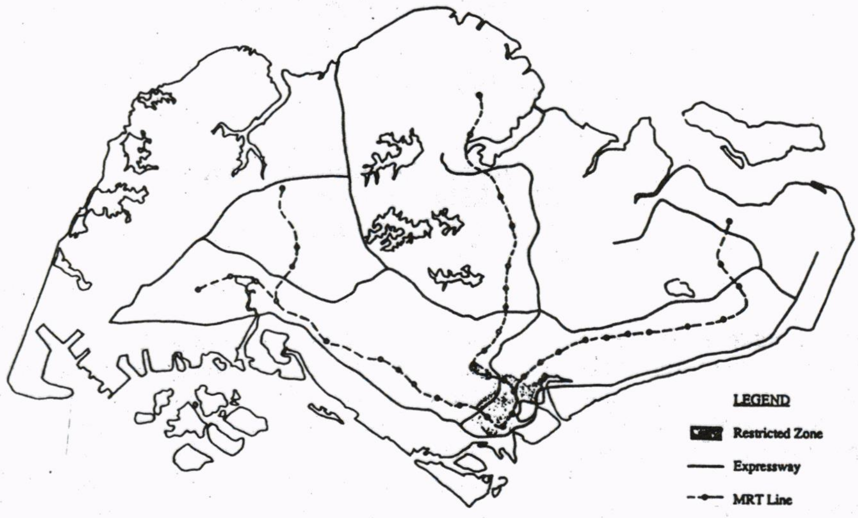

Figure 1 The mass rapid transit lines, expressways and restricted zone in Singapore.

ITS refers to the use of advanced technologies, such as information processing, communications, control, electronics and etc. in a systematic and co-ordinated fashion in helping to ease the problem of urban traffic congestion and increase mobility. Formerly known as the intelligent vehicle-highway systems (IVHS), ITS has gained wide acceptance by researchers, engineers and public agencies in the United States, Japan and Europe in the past few years. The Intelligent Vehicle-Highway Society of America (IVHS America) was formed in 1990 to plan, promote and co-ordinate the development and deployment of IVHS in the United States. In 1991, the U.S. Congress approved US$600 million budget for IVHS program for six years, with a 20-year forecasted total expenditure of US$209 billion (IVHS America, 1992; Constantino, 1993). IVHS America was renamed as ITS America in 1994. In Europe, two major programs, namely the Programe for a European Traffic with Highest Efficiency ad Unprecedented Safety (PROMETHEUS) and Dedicated Roadway Infrastructure for Vehicles in Europe (DRIVE) are dedicated for the development of vehicle technology and highway management, respectively. The European initiatives are co-ordinated by the European Road Transport Telematics Implementation Co-Ordinating Organization (ERTICO). In Japan, it is reported that ITS type of development has been initiated as early as 1972 (Ervin, 1991). The Japanese ITS program appears to focus on in-vehicle travelers information, with projects like Advanced Mobile Traffic Information and Communication System (AMTICS), Road Automobile Communication System (RACS) and Super Smart Vehicle System (SSVS). The goals for ITS is to improve safety, reduce congestion, increase mobility, reduce environmental impact, improve energy efficiency and indirectly improve a nation's economic productivity. The six recognized areas of ITS are:

Advanced Traffic Management Systems (ATMS)
Advanced Traveller Information Systems (ATIS)
Advanced Vehicle Control Systems (AVCS)
Advanced Public Transportation Systems (APTS)
Commercial Vehicle Operations (CVO)
Advanced Rural Transportation Systems (ARTS)

Singapore, being a country with limited resources, could not be expected to compete with U.S., Japan and Europe in ITS research. However, its social and political uniqueness make it an ideal city to implement several components of ITS. This paper discusses the proposed and on-going projects that relate to ITS, and how they fall into the ITS functional areas of ATMS, ATIS and APTS. The potential expansion of these projects to suit local transportation needs and their likely problems will be highlighted. Solutions to overcome some potential problems will also be suggested.

2. ADVANCED TRAFFIC MANAGEMENT SYSTEMS (ATMS)

2.1 Electronic Road Pricing

Road pricing was first implemented in Singapore in 1975 (Watson and Holland, 1978). The system, called Area License Scheme (ALS) is based on cordon pricing where vehicles (except for public buses) have to purchase and display area licences to enter a restricted zone during certain hours. The restricted zone is approximately 725 ha in the central business district (see Figure 1) and is demarcated by 33 overhead gantry signs at its entry points. Currently the hours of road pricing operations are 7:30am-6:30pm Mondays to Fridays, and 7:30a.m.-2:00p.m. on Saturdays. The area licences can be purchased at sales booths located at the boundary of the restricted zone, and at selected petrol stations. The licences are S$3 for full-day and S$2 for off peak period from 10:15a.m.- 4:30p.m. Mondays to Fridays and to 2:00p.m. on Saturdays. Monthly pass is also available. The ALS is enforced by deploying police officers at each entry point. Vehicles failure to display a valid area licence will have their vehicle licence numbers noted down.

The current manual sales and purchase of area license, and enforcement method will be replaced by the Electronic Road Pricing (ERP) system in 1997. The proposed ERP system consists of three main components as shown in Figure 2: in-vehicle units, entry point equipment and a central computer (Lew *et al*., 1994). All vehicles will be fitted with the in-vehicle units, in which a pre-paid smart card will be inserted. Two gantries, each with a vehicle detector and communication antenna for individual lane, will be erected at each entry point to the restricted zone. Communication between the central computer and in-vehicle units will be through the local controllers and antennae. A vehicle approaching the first gantry will be sensed by detector. The local controller would instruct the in-vehicle unit to deduct an entrance fee from the smart card. As the vehicle is traveling between the two gantries, the local controller will check the balance of smart card, and prepare a transaction message. The message is then relay to the in-vehicle unit via the antenna at the second gantry. Photographs of offending vehicles will be taken by cameras installed on top of the gantry. The system is designed for high speed entry of up to 120 km/h and to protect the privacy of vehicle owners.

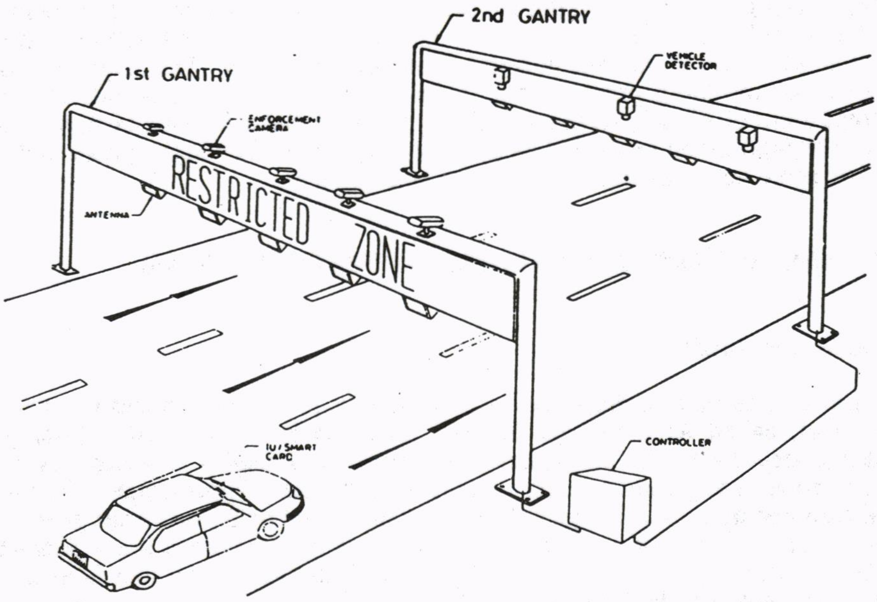

Figure 2 Components of the Singapore electronic road pricing system (from Lew *et al*., 1994)

It is natural for the initial ERP system to replace the ALS which has been successful in the past 20 years. The toll charges of the ERP will probably based on the vehicle class and time of entry for ease of enforcement and public acceptance. Future modification could involve charging fees based on historical traffic pattern in the restricted zone, and even real-time dynamic road pricing. In the later case, traffic data such as speed and occupancy collected within the restricted zone can be used as parameters to decide the toll. The entry point equipment of the system is designed such a way that it can be installed in any location of the road network, permitting the expansion of the toll collection points. One way of expanding the ERP system is to designate one or several ring areas surrounding the current restricted zone. Motorists will be charged progressively as they approach the "core" restricted zone from outlying origins. This will prevent the problem of overcrowding of streets immediately outside the restricted zone.

It would not be difficult to foresee that ERP be implemented at expressways and major streets where recurring congestion occur on daily basis. In fact, the Government has recently implemented a pilot road pricing scheme similar to the ALS at one segment of an expressway leading into the city (Straits Times, 1995d). Such scheme, together with dynamic toll fee provides a more equitable method of charging motorist for road usage in addition to road tax and registration fees.

2.2 Incident Management

Besides road pricing, the Public Works Department (PWD) is in the process of converting all traffic signals under real-time control (Straits Times, 1994b). Currently, more than half of 1200 traffic signals are already under a control system called GLIDE (for Green Link Determination), which is based on the SCAT system (Chin, 1993). GLIDE system collects data from loop detectors at stop lines, and make adjustment to signal timing. It is no doubt that GLIDE is one of the most advanced traffic signal control system. While real-time control of traffic signals can adapt to the traffic demand and reduce delay, its benefits would be lessen in the event of incidents or operational problems (such as illegal parking near intersection, spilled back of left-turning queue onto the through lane).

Most of the existing signal control systems in the market lack capability to detect and response to incidents. If such incident does occur, personnel in the traffic control center can only make an inspection on detector data and deduce the likelihood of event occurring in the field. With more than 1200 signalized intersections under a centralized control in the near future, multiple occurrences of incidents during a peak period can easily cause operator overload. A real-time decision support system with capabilities to automatically detect incidents, make suggestions on the response strategy (such as sending a emergency response team to the site, providing warning and detour information via radio and variable message signs), and continue to monitor the post-incident scenario would provide relieve to the personnel. A similar prototype system has been developed for the Disneyland area in Anaheim, California (Deeter and Ritchie, 1993). To perform incident detection on arterial streets, additional detectors are required at upstream of a link. The vehicle detectors at ERP gantries may be used to collect traffic data to supplement inductive loops of the GLIDE system. The PWD will be installing surveillance cameras at 15 major intersections (Sunday Times, 1995a). These cameras can also be used to supplement loop data and give visual confirmation of incidents.

Singapore currently has approximately 120 km of expressways, of which 2.4 km are underground tunnels. The tunnels are being monitored and control with video cameras, loop detectors and variable message signs. It is possible that in the future, AI-based video detection system be implemented in the surveillance system and the system be expanded to all expressways (Sunday Times, 1995b) under a decision support system for expressway incident management. The long term road master plan calls for an underground ring road of 15 km be built around the city (Straits Times, 1994a). With the proposed tunnels, surveillance and control functions becomes critical in day to day operations. The expressway traffic management system must also be capable of co-ordinating with the arterial traffic management system, ERP and GLIDE during major incidents where large scale traffic diversion is necessary.

Unlike the cities in the United States, Singapore has the advantage of having most, if not all traffic management tasks under the jurisdiction of PWD. The inter-jurisdictional co-operation for ERP, GLIDE, expressway and arterial ATMS integration is thus minimal. There are several foreseeable issues or problems which should be addressed if the above proposed systems are to be implemented smoothly. First, it is unknown what level of ERP toll is acceptable to the public, although initially motorists would accept a fee similar to that of the ALS. Secondly, it would not be easy for the authority to convince the motorists that dynamic road pricing is the most equitable way of charging for road usage. A proper pricing formula has to be developed. Two pre-requisite of using video cameras for surveillance are the present of tall structures and unobstructed field of view. Singapore is not lack of tall buildings, even in residential estates. However, trees planted on roadside to provide shades and greens could cause obstruction of the camera view. The technology of video image processing for traffic analysis is yet to be perfected. Although it would be of management and motorists interest to have a video image processing-based traffic surveillance system, it may be advisable to wait for the technique to be fine tuned with operational experience learnt in other cities.

3. ADVANCED TRAVELLER INFORMATION SYSTEMS (ATIS)

Advanced traveller information system (ATIS) usually refers to in-vehicle information system which facilitates pre-trip planning and on-board navigation for private vehicle drivers. In Singapore, ATIS will first be implemented by means of automatic vehicle location (AVL) by taxi companies.

At present, Singapore has approximately 13,000 registered taxis operated by three major companies. The largest taxi fleet belongs to COMFORT Group Ltd (COMFORT), with fleet size of over 9000 vehicles. More than one-third of which are fitted with on-board radio to facilitate voice communication with the dispatch center. COMFORT is planning to automate its dispatching system for 3000 taxis. The proposed system makes use of global positioning system (GPS) to track vehicles (Straits Times, 1995b). A customer can dial for a taxi from a push button phone and key in the necessary information. The computer dispatcher will locate the nearest available taxi through the GPS, and instruct the driver of the origin and destination. A similar system is on the drawing board of CityCab Pte Ltd, the second largest taxi company with more than 3000 vehicles. Operational tests for these advanced dispatch systems are scheuled to commence in late 1995 or early 1996 (Straits Times, 1995b, 1995c). Instead of the proposed systems which are mainly designed for subscribers at homes or offices, a simpler version of the system can be implemented at taxi stands at major shopping malls, major transportation hubs and taxi demand generators. In this sub-system, a pushed button at a taxi terminal will send a message to all available taxis within an area (say 2 km radius) to inform them of a demand for service. The demand is canceled when certain supply conditions are fulfilled, e.g. loop detector detects a taxi queue, or a number of taxis answer to the calls.

To date, it is not known if the taxis will be equipped with on-board navigation devices, such digital road maps and graphical display panels. To the very least, alphanumeric display panel should be available to inform the drivers of the points of taxi demand. Existing radio communication equipment should continue to function. Since taxi companies are profit oriented, it is of their interest to locate the nearest customer as soon as possible, especially with the full scale ERP system in place. Commuters also enjoy an advantage of knowing the shortest route from an origin to a destination and the estimated fare, based on the prevailing traffic conditions.

The traffic data collected from the abovementioned ATMS facilities can be used to deduce travel time. Since GPS will be used in taxis, and with thousands of them, taxis can serve as probe vehicles traveling island wide, thus providing real-time travel speed to supplement stationary sensors. In addition, the probe vehicles can also function as incident detection devices which provide feedback to the ATMS system. The vehicle positioning systems, if successful, can be extended to civil defense vehicles (e.g. ambulance, police patrol vehicles, fire engines and etc.). Such service can also be marketed to private industries to provide additional revenue to taxi companies.

The use of GPS for continuous vehicle positioning is not without problem. The GPS system is based on 24 U.S. Department of Defense satellites. Currently the signals are transmitted free of charge for civilian use. It is uncertain if the satellite signals will be available in the long term. To calculate the instantaneous co-ordinate of a vehicle, the receiver needs signals from at least three satellites simultaneously. The satellite signals could be occluded by tall buildings, trees and overpasses. It is also not possible to receive these signals in tunnels. The Japanese experience has shown that using beacons and dead reckoning is a viable alternative (Yumoto and Liu, 1994).

4. ADVANCED PUBLIC TRANSPORTATION SYSTEMS (APTS)

In Singapore, public transportation includes mass rapid transit (MRT) and bus. The Singapore MRT system started its operation in 1988 and currently has 42 stations and 67 km of track. Public bus services are being provided by two major bus companies: The Singapore Bus Services (1978) Ltd (SBS) and Trans-Island Bus Services Ltd (TIBS). These two companies have a combined bus fleet of more than 2600 vehicles servicing 240 routes. There are several bus companies plying relatively smaller number of routes. ITS has high potential to be applied to (i) advanced fare collection system for bus and MRT; and (ii) real-time bus passenger information system.

4.1 Advanced Fare Collection System

The MRT, SBS and TIBS commuters use an integrated ticketing system provided by Transit Link Pte Ltd (Segaran, 1994). With this system, passengers use one type of pre-paid stored-value farecards for two modes of public transport. Each card has a magnetic strip that records the credit balance, time and location of the current and last trips. Ticketing machines are installed in buses and MRT stations. The ticketing machines deduct trip fare from a fare card at the beginning of a trip for buses or at end of a trip for MRT. Transfer passengers are given discount. The trip information is recorded by individual ticketing machine and then transferred to a central ticketing computer for processing. This integrated ticket system captures individual trip data made by MRT or bus, including the origin, destination, mode and travel time, and is a comprehensive data set for public transportation planning.

Existing bus ticketing machines are installed at passenger entrances. Each passenger has to insert his or her fare card into a slot, push the appropriate button for the desired fare, and pick up the bus ticket and fare card at the dispensering slot. At present, bus fare is divided into 6 stages based on trip distance (e.g., from S$0.50 for the first 3.2 km up to S$1 for 14.4 km and longer, for non-air-conditioned services). With the typical bus stop apacing of 400 m and the stage fare structure, the alighting point of a bus passenger can only be approximated based on the paid fare. The fee paying system works more like a honest system, with relatively few ticket inspectors to conduct random check on board. One recent study reveals that the average dwell time for such a fee paying operation takes 1.9 sec per passenger (Tan and Fan, 1995). To reduce the dwell time, existing ticketing system could be replaced by contactless smart cards for automatic fare collection. With this method, the stored-value fare cards are replaced by smart cards while the ticketing machines by scanners/transmitters at the bus entrances and exits. A passenger only needs to hold his or her smart card under a scanner upon boarding. The boarding time and location will be transferred to the smart card. During alighting, the smart card will be scanned by the machine at the exit door, where the correct fare will be deducted. Thus, without physical contact, dwell time is reduced, the fee payment is being enforced and fare structure can be set to smaller increments. This will also enable the central ticketing computer to have the exact alighting bus stop of each passenger, resulting in a more accurate database for transportation studies.

The fare card system works in the MRT system in a slightly different way. Ticketing gates are installed at platform entrances and exits. Each passenger inserts the fare card into the reader at a ticketing gate upon entering the station platform. The origin station's identification and time are recorded onto the fare card. The fare card is then returned to the passenger. Upon retrieving the fare card, the gate is open momentarily for the passenger to enter the platform. At the end of the trip, the correct fare is deducted from the fare card at the exit gate by the same process. Compared to the bus ticketing system, the MRT system collects data at the end point of each trip. To avoid bottleneck at ticketing gates during a station's peak hour, the Singapore MRT Corporation is experimenting with two smart card readers at a station. The corporation has set a target to convert 80% of the fare gates with smart card readers (D'Aranjo, 1995). With this progress, an integrated advanced fare collection system with smart card technology is in the horizon.

4.2 Real-Time Passenger Information System

Currently, SBS has video display of bus departure information and electronic bus guide at major bus terminals. However, such information are static. In response to public demand, SBS will be implementing an en-route passenger information system (Straits Times, 1995f). The system, named SBS OnTime, will provide bus route and arrival time information on electronic display boards at major bus stops. The SBS OnTime is similar to the systems being tested in Paris (Briolat, 1995) and Minneapolis (Kilroy, 1994).

Since buses always ply along a fixed route, locating the positions of buses becomes relatively easy. The basic components of the SBS OnTime system should consist of terminal display units at bus stops, road side positioning beacons, in-vehicle beacons, and a central computer. Buses passing roadside beacons will have their identifications and positions transmitted to the central computer, which will send messages to relevant roadside terminal on the estimated arrival times. The central computer will also inform drivers via in-vehicle display units on whether the buses are on time, ahead or behind schedule, and possibly the necessary diversion in response to severe traffic congestion. Initially, SBS proposed to use GPS for vehicle tracking. Due to the difficulty of using GPS in the build-up area as discussed above, the use of road side beacons or a combination of GPS and roadside beacons may be more feasible.

The OnTime system has potential to integrate with the ticketing system on board of buses. For example, with the current ticketing system, the load factor of a bus at any point on a trip can be estimated from the cumulative passenger arrival and departure patterns. The bus occupancy can be estimated even more accurately with the contactless smart card system discussed in the previous sub-section. This information can be given to the OnTime system to display the level of occupancy of the coming buses. This gives the waiting passenger an option to wait for the next service, take an alternate bus route, or change the mode of travel. The central computer can also warn the fleet management personnel on overcrowding of certain services, thus enable them to dispatch more buses to pick up passengers at the locations which have high demand.

Besides SBS, TIBS has also announced its interest in the vehicle tracking, and plans to implement its own system. In Singapore, major bus companies share the use of bus stops along their routes. Maximum economic efficiency could not be achieved with the two companies each operating its own AVL systems. Besides, the roadside beacons can also be used by taxis. It appears that COMFORT, CityCab, SBS and TIBS vehicle tracking systems are in competing mode. A consortium which consists of bus, taxi, and telecommunication companies should perhaps be set up to co-ordinate and regulate the island's vehicle tracking infrastructure, especially the roadside beacons and related landside communication facilities.

The advanced fare collection system and real-time passenger information system can reduce travel time and in some ways improve public perception on bus travel. However, it should be noted that the speed of bus travel in mixed traffic still depends on the prevailing traffic conditions. In the past, the Government policies are related to demand management for private passenger cars. In the future, the emphasis will shift towards improving public transport, making it a more attractive mode. To this end, we are likely to see more ITS applications in public transport, for example, bus priority signal, or even in light rapid transit.

5. DISCUSSIONS

From the above discussions, it can be seen that although Singapore is not competing with United States, Europe and Japan in ITS research, the Government, public and private sectors are actively involved in the deployment of certain ITS components. It is also unfair to say that Singapore is not investing heavily in ITS. The initial cost of the ERP system will be above S$185 millions (Straits Times, 1995e), and maintenance cost for the first five years will have a minimum sum of S$38 million (Straits Times, 1995a). These figures are based on the lowest bids submitted in the tenders. The costs do not include the price of in-vehicle units, which will be borne by vehicle owners. The construction of underground ring road will cost approximately S$4.8 billion (Straits Times, 1994b), a fraction of which will be devoted to the traffic surveillance and management system. The COMFORT's GPS-based taxi dispatch system is estimated to cost S$5 million (Starits Times (1995c), while that for the CityCab will cost S$20 million (Straits Times, 1995b).

In addition, several light rapid transit systems will be constructed in the next decade to supplement the MRT and bus systems.

The ERP, incident management, taxi dispatch systems, advanced bus fare collection system and real-time passenger information system are not independent from each other. Integration of information can produce system wide benefit. For example, to implement dynamic ERP successfully, drivers need to be informed on the spatial and temporal distributions of toll charges through in-vehicle ATIS, variable message signs, radio and television channels, or other means of communication. The level of sophistication of the ERP system therefore depends on the success and market penetration of ATIS.

Unlike the United States, Europe and Japan, which have their national or regional ITS programs, the ITS projects in Singapore appears to be independent from each other at the time of writing. To optimize the deployment of resources and infrastructure investment, there is a pressing need for a national body similar to the ITS America to advise and develop a national ITS architecture, oversee funding, co-ordinate activities, and promote local industries (especially the electronic, manufacturing and telecommunication industries) to participate in ITS. The Government of Singapore has recently formed the Land transport Authority (LTA) to oversee all land transport policies and infrastructure (Straits Times, 1995g). The LTA could take the lead in organising such effort.

The ITS activities in Singapore can also be viewed as information management in land transport. From this point of view, the ITS development plan is well in line with the Government's IT2000 plan on building up information infrastructure in Singapore.

6. SUMMARY

Although lagging behind in ITS research, Singapore is very active in pursuing deployment of ATMS, ATIS and APTS. It will be among the first countries to have an operational ERP system and GPS-based taxi dispatch systems. Advanced fare collection system and bus passenger information systems are being planned. Other ITS components, such as incident management systems, has high potential to be implemented. In order to realize the full potential of ITS, various ATMS, ATIS and APTS components have to be integrated. At present, several ITS related projects appear to be independent and even competing with each other. There is a need to co-ordinate these developments in order to make full use of the traffic information. The development of ITS activities and possible expansions have opened up many opportunities for future research.

DISCLAIMER

The content of this paper is solely the opinion of the author and does not necessarily reflect the views of the authorities and companies mentioned.

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