A Smart City Transportation System of Systems Governance Framework: A Case Study of Singapore

Oon Ling, Lee
The University of Adelaide
Singapore
valerie@machex.com.sg

Rick Im, Tay
Maritime Port Authority of Singapore
Singapore
desmond_tay@mpa.gov.sg

Shing Tsair, Too
Exxonmobil
Singapore
marcus.shingtsair.too@exxonmobil.com

Professor Alex Gorod
The University of Adelaide
Australia
alex.gorod@adelaide.edu.au

***Abstract* – As increasing economic, technological and infrastructural development takes place in smart cities, there is an immediate need for a transportation governance framework for smart cities. The land transportation system in smart cities can be viewed as a system of systems that consist of constituents that are autonomous, belonging, connected, diverse and emergent, with one common objective to transport passengers in a safe and efficient way. This paper will introduce a new system of systems governance framework, using Singapore as a case study to illustrate how the existence of an effective governance of "system of systems" can allow smart cities to operate efficiently and effectively.**

I. Introduction

Many smart cities such as Amsterdam, London, Seoul, Stockholm, Tokyo and San Francisco [1] are facing increasing challenges in effectively managing their complex transportation networks. Rapid urbanization and motorization have resulted in tremendous problems and pose daunting challenges to these cities. Smart cities transportation networks are plagued by tremendous traffic jams, poor commuter security and safety as well as inefficiencies. The increasing interest in smart cities has triggered plenty of smart city solutions such as planning support systems (PSS) and transport modelling framework such as PECAS (Production, Exchange, Commodity Allocation System (PECAS) applied to many cities, states and provinces in North America and act as a planning tools in smart cities like China [2]. Despite many countries trying to adopt these solutions to alleviate the transportation system problems, the main barrier to adopt these solutions is the complexity of how the smart cities are operated, regulated, financed and planned [3]. Hence, this present an opportunity to integrate a concrete system of systems governance framework with the existing solution, to enhance the management of these transportation network [4]. Singapore, ranked second in the world with the best transportation system, has done better than most countries in the world [5]. This paper will first discuss the major transportation challenges faced by smart cities, followed by the use of Singapore as a case study to illustrate how the system of systems governance framework can be applied. Finally, the paper will make specific recommendations on how this new governance framework can complement existing solutions to enhance the transportation system in smart cities.

II. A Smart City Transportation System

A. The benefit of a governance framework

There is a direct relationship between the economy and the efficiency level of a transportation system. A high-density transportation network is closely associated with high levels of development. An efficient transportation network provides economic and social opportunities, resulting in multipliers effects of better market accessibility, employment, additional investments and increased job opportunities; while for businesses, an efficient transportation network can help reduce cost [6].

B. Challenges Faced by Smart Cities

A smart city is defined as a municipality that increases operational efficiency, information sharing with the public and improves government service and citizen welfare through information and communication technologies [7]. As such, smart cities face major challenges in managing their transportation system (Table 1), including lack of credible public transportation options, a need for centralization of the transportation system, safety and security concerns and the need to ensure the sustainability of the transportation system.

C. Lack of Smart Cities Transportation Governance Framework

A strong governance transportation system will allow smart cities to actively grow their economy by a significant quantum [12]. Smart cities around the world have adopted technologies to assist them in governing their transportation systems. For instance, Skope, a traditional Macedonian city [13] has benefitted from several non- motorized solutions via leveraging on smart technology like e-vehicles and adaptive transport system to improve its current economy. However, reliance on new technologies is insufficient in the growing complexities of transportation demands. A strong governance system by a government-initiated body, backed by a legal framework will allow smart cities to successfully address these challenges and improve the lives of their people in a sustainable manner [14]

III. The Case of Singapore

Since 1970, the demand for public transportation has grown tremendously in Singapore. Coupled by the land constraint, the population density had witnessed a significant increase from 3.5 million (1970) to 7.04 million (2018) per square km [15]. This resulted in commuters having to live in highly congested public transportation environment, especially during peak hours. The traveling time using public transportation has become longer, leading to inefficiencies and decreased productivity.

TABLE I. THE MAJOR CHALLENGES FACED BY SMART CITIES

S/N	Challenges	Challenge Descriptions
1	**Lack of credible Public Transportation Options**	A sudden increase in population or the influx of immigrants often leads to a sudden pinch point. Overcrowding on trains/buses in Europe and Hongkong are common points and the low reliability of such systems contributed to significant losses of efficiency for the economy [8]
2	**Centralization of the transportation system**	To incorporate all the systems into the main system (e.g. cameras, vehicle detectors, messages signs, radio signals). This is a key factor similar to the arteries of a heart system to ensure round-the-clock coordination and communication to reduce city congestions with an accurate prediction on a path forward [9]
3	**Safety and Security**	Potential terrorist attacks and invasion by rogue neighbors, and aging infrastructure. Reliance on critical infrastructure to manage daily operations show that accidents and fatalities arise due to inefficient systems deployed in countries [10]. There are also issues of violence and sexual crimes committed on public transport.
4	**Sustainability of Transportation System**	The lack of available land and to build new transportation networks often hinders the planning and development of long-term transportation solutions. [11]

Public transportation infrastructures such as roads and railways are strained, to cope with the increased human traffic. The public perceived the cause of congestion to be partly due to the increasing population over time.

The taxi system is operated by seven companies – Comfort Taxi, CityCab, SMRT Taxis, TransCab, Premier Cab, Prime Cab and Yellow-Top Taxis. Their existing business competition has recently been elevated by the emergence of sharing economy models like Grab, Uber and Gojek. Commuters can easily book their rides at cheaper rates with private hired car services using mobile apps. The introduction of these private car hire services has resulted in an increase average rate of idle taxis, from 4.2 percent in 2015 to 5.9 percent for the first 11 months in 2016. Although the situation has improved after the exit of Uber, it was reported in The Straits Times that more than 1,620 taxis are currently sitting idle in the yards of taxi companies, up from 1,190 [16]

With the increasing affluence of the population. more vehicles on the road are used for daily personal commuting and business purposes. More traffic jams are experienced during peak hours. On the other hand, the government implements measures to control the traffic, such as the issuance of Certificate of Entitlement (COE) to car owners, deploying the Electronic Road Pricing (ERP) mechanism at highly congested roads. All these measures have led to an increase in the cost of owning and using a vehicle for personal or business users.

D. Establishment of Land Transport Authority

The government set up the Land Transport Authority (LTA) since September 1995 to spearhead improvement to Singapore land transportation system. The main objective of the government is to develop a world-class transportation system that provided commuters with high-quality service, yet accessible, affordable and convenient rides in free-flowing traffic. Over the past 30 years, the city has grown to accommodate a wider spectrum of transportation system consisting of trains, buses, taxis, private cars and commercial vehicles that are effectively integrated with one another. The government has also set a benchmark for the nation to maintain competitiveness with other countries.

E. Problems Statement

Although the system has been developed over 30 years, issues still arise when the system interacts with other systems or external factors come into play. In the social context, the land transportation system will provide positive multipliers to its people by providing more employment opportunities. As more new technologies are adopted into the land transportation system, there is a need to improve the manpower quality through education and upskilling of public transportation employees.

In recent years, the failure rate of the Mass Rapid Transit (MRT) train system is gradually increasing. There were many instances of entire railway line failure of up to 4 hours, causing massive congestions, commuters' inconvenience and loss of productivity at stations. Investigations into the failure issues of the MRT train system revealed fairly commonplace weaknesses - worn cable insulation, tunnel water leakage, and a glitch in a power substation switch. This proved a lack of skilled engineers in the maintenance aspect of the train system. There was no proper maintenance schedule, comprehensive coverage of work scope or talented engineers with good experience in the field. The failure of the MRT train system led to a sudden influx of commuters, mounting tremendous stress on alternative public transport system – the bus system, which was then used as the alternative transport mode. This evidently created more congestion issues in an already crowded bus system. The hub-and-spoke design between MRT and Bus system caused a reduction in direct bus service routes between major transport nodes hence, commuters needed to make multiple switches on a few buses to arrive at their final destination. The frequent train breakdowns had resulted in the low satisfaction rate in the annual commuters' survey.

F. Government intervention

The widespread commuters' dissatisfaction of the public transport performance caused the Singapore government to manage the MRT train system directly. Besides the government taking over the operator of the train system in Singapore, a series of intervention measures such as the Bus Service Enhancement Program (BSEP) was rolled out, where

S$1.1 billion (equivalent to USD 0.82 billion) were used to purchase 1000 new buses to enhance efficiency with 65 new service routes introduced in 2016. The maintenance issue of the MRT train system was a rising concern of government. They were very concerned with the rail operator's ability to fund the maintenance and replacement cost. Initially, the government governed the railway infrastructure through LTA, so that the operator can maintain their fares, to allow the public to enjoy low-cost transport. However, their continuous poor performance led to several major disruptions which resulted in the government buy-back to fund the maintenance of the MRT system. This became a conflict to the government's initial objective.

IV. New Governance Framework

Although the land transportation system in Singapore has been relatively well-managed compared to many countries, they have the potential to be more efficient, given a strong governance framework to work on. In this section, the paper will discuss the classification of the Singapore Land Transportation System (SLTS) as a system of systems using a systemigram (Figure 1) to illustrates the main entities and relationship within the SLTS, followed by the introduction of a new governance framework (Figure 2), depicting the governing body and the SLTS to concretize this approach.

G. Classification of SLTS as a system of systems

The SLTS is classified as a system of systems that comprises of multiple independent constituents, interacting with one another to deliver unique capability [17]. Each constituent in the SLTS, namely the train system, bus system, taxi system and road system can produce results independently in transporting commuters; however, by working together, these constituents will provide more choices and greater flexibility in meeting the needs of commuters. The SLTS displays varying degree of autonomy, belonging, connectivity, diversity and emergence behaviour.

Each constituent system has a high degree of autonomy to plan, design and build its network to meet the government's objective of achieving a world-class transportation system. Train operators have the ability to develop their own train operation system from maintenance, train schedules, traveling time to safety policy etc. Bus operators are more flexible when it comes to changing the travelling route. These changes are sometimes necessary as the demographics of the town may change with the increasing population growth. Unlike the train system, bus system will require forward planning method in the network design. It will be very expensive to change the infrastructure once it has been constructed.

The train, bus and taxi transportation network are so dynamically connected with one another that commuters are able to change their mode of transportation conveniently. At each train station, there are multiple buses with different travelling routes to choose from. Taxis from different companies are also connected to the train station to provide an additional choice of transportation. The private road users can also interact with the bus and taxi transportation via the road system.

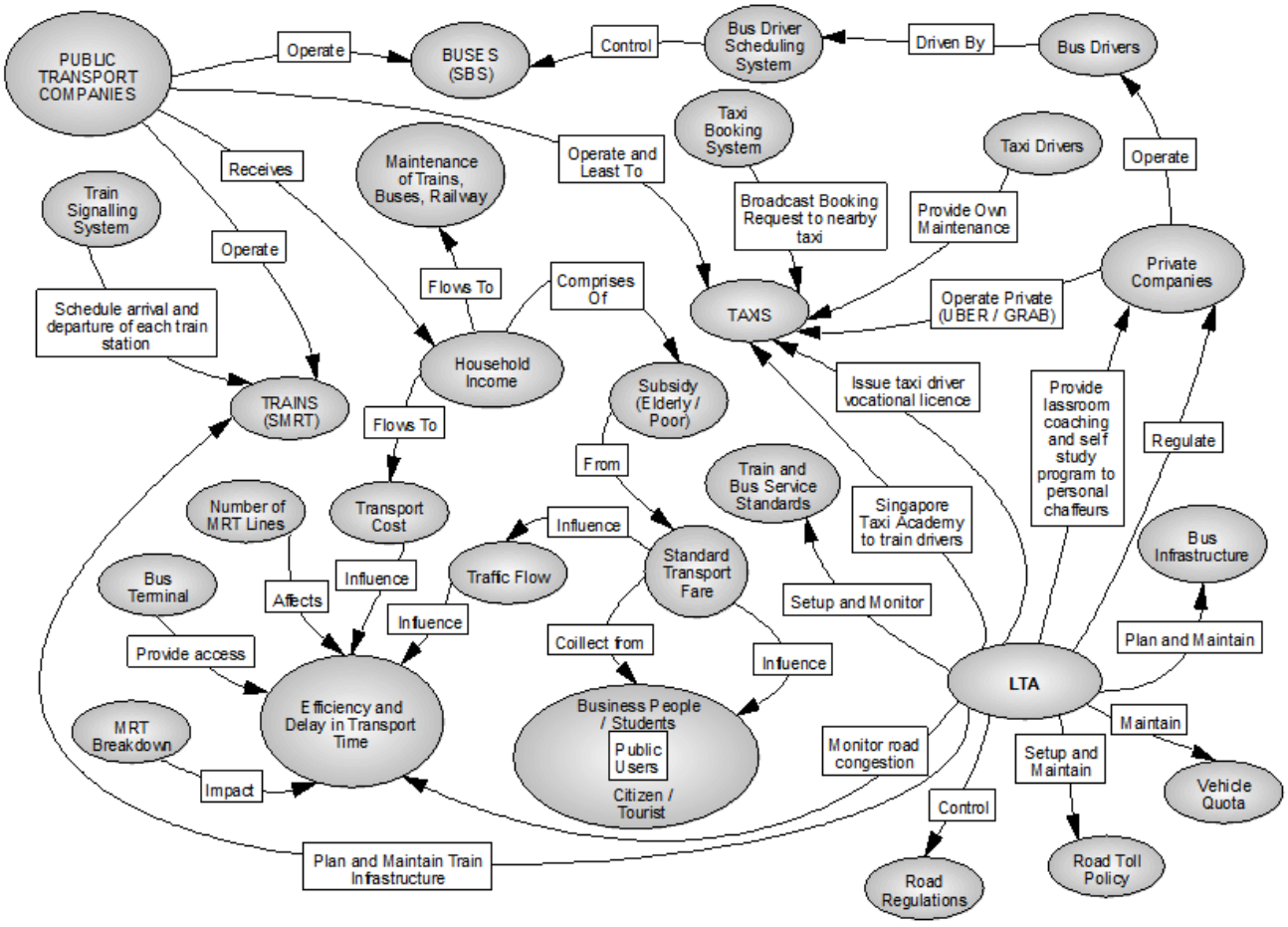

Figure 1. Systemigram of Singapore Land Transportation System of Systems

H. System Description

To understand the complexity of SLTS, we can adopt the layering framework use of agent-based modelling by breaking down the SLTS into three layers. The first (top) layer is the physical layer formed by commuters, different vehicle types and land transport infrastructure that creates the dynamic connection and interaction between entities in the SLTS. For instance, commuters can make use of public transport, taxis or private vehicles to travel around. They are connected to their destination through the roads or railway tracks. The second (middle) layer is referred as the organizational layer, a layer that defines the skill, knowledge and financial ability to manage and operate the physical layer. They can also be defined as the railway and road management, facilities management, safety and health management that can be found within the different organizations. For instance, the public transport companies that operates the SLTS are tasked to operate public transport services for the commuters. The taxi drivers and private car-hire drivers operate and manage the taxis and private car-hires services independently. The third (top) layer refers to the governing body, formed by the relevant government bodies and public agencies that regulate the interaction and movement in other layers. In SLTS, the top layer consists of Land Transport Authority (LTA), Ministry of Transport (MOT), Ministry of Finance (MOF) and Public Transport Council (PTC), who are the governing body that ensures the SLTS is operating at its optimum level and provide good performance, service level and reasonable fare and satisfy legal requirements. Basically, the governing body builds the land transport infrastructure and engages public transport companies to operate the services at a fee. All fares collected from the services are then returned to the governing body.

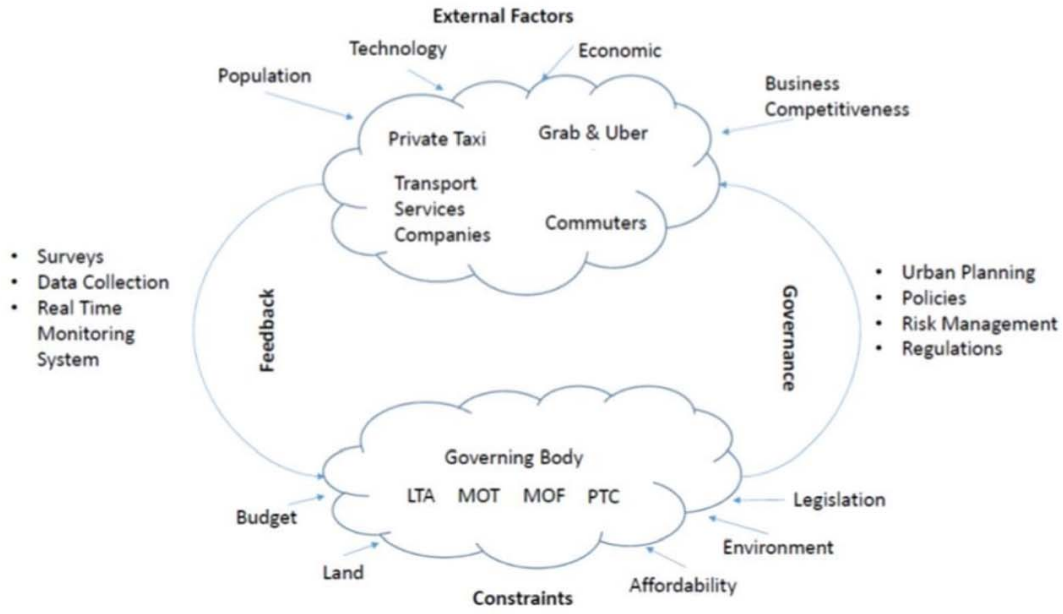

Figure. 2 The New Governance Framework for the Next Generation Smart City Transportation System

I. The Governing Body

The government of Singapore is the sponsor of the SLTS. LTA is a public agency that the government tasked to plan, build, operate and manage the existing land infrastructure and transportation systems [18] through policy making and regulations. LTA will also recommend and plan future land transportation expansions based on certain government parameters, such as the zero-rated growth on the amount of Certificate of Entitlement (COE) for private vehicles and slowing down the growth of building roads. The government will provide grants from their annual budget to the LTA for their operations [19].

Besides LTA, the governing body also include MOT, MOF and PTC. These organizations have a significant impact on the SLTS especially those associated with the public transportation systems – Bus, MRT and Taxi. LTA will work with MOT to plan, design and develop the land transportation infrastructure such as roads, bus stops and bus terminals. MOT will liaise with MOF on the budget for these land transportation infrastructure projects while PTC will regulate public transportation fares and public ticketing services and plays the role of an advisor to the MOT on public transportation matters.

LTA is a "holon", part of a wider system involved in the development of the nation. In transforming the SLTS through the LTMP 2013, LTA has engaged other agencies such as Urban Redevelopment Authority (URA), National Parks Board (NParks), Public Utilities Board (PUB) and Housing Development Board (HDB), in its' planning. LTA will engage these agencies through a planning steering committee; where all agencies have a voice in the development of LTA's strategic planning. "Holarchy" can be observed in such situation where the "holons" are arranged in a hierarchy linked by a system of communication and control. The National Cycling Plan is a good example of the collaborative effort involving these agencies to make cycling an alternative transportation option for Singaporeans. LTA also works with

URA to mandate developers to incorporate bike parking and shower facilities into their building design [20].

J. Govening Constraints

Budget Constraints - The operating budget for SLTS can be divided between LTA, the representative of the government, the system owner and the public transportation companies, providing the transportation services to the nation. LTA's operating budget comes from operations income and government grants to assist them in building and maintaining the infrastructure. These budget was set aside yearly to maintain the existing infrastructure, upgrading work and project implementation, shared across construction, roads, airport upgrading. The total land transportation expenditure in 2017 was $9.17 billion – more than five times that of a decade ago [21]. The allocated budget was insufficient to meet all objectives, so priority will be given to the important ones.

Boundaries Constraints - This system is envisioned to cover the whole of mainland Singapore. The outer islands are excluded from this system. The island is a network of roads, expressways traffic lights, MRT stations, MRT depots, bus stops, bus terminals and cycling paths. The network creates a boundary that is shared between the people who drive, cycle or take public transport. The legislation, regulation and rules are set by LTA to enforce the orderly functions of each constituent component. The network complexity will increase when LTA decides to build more physical infrastructures or develops new bus services, This complexity will also increase when new towns are being developed by Housing Development Board (HDB) or Urban Redevelopment Authority (URA) due to the need to construct land transportation infrastructure to facilitate travel within the new towns and to integrate these new towns to other parts of the island.

Land Constraint - Singapore has a population of 6.5 million today and a land size of 719 square km. Land scarcity is a serious issue that governing bodies need to manage. Railway network expansion is limited by the available spaces above and below ground. Architects and land planners faced great challenges integration land with existing land transportation network.

Affordability Constraint - Public transportation should be made affordable to everyone in Singapore, hence cannot operate on a cost-plus basis because inefficiencies will be translated into higher fares [22]. Large scale projects involving high capital cost will be funded by the government. To meet the national agenda, the government needs to ensure that the operators are charging affordable rate to the commuters, without compromising the recovery of its operating cost.

Environmental Constraint - Global warming is primarily a result of excess carbon dioxide in the atmosphere caused by fossil fuels burning [23]. On one hand, the government has a responsibility to protect the environment. On the other, it must build a stronger economy with constant population growth, which translate to higher land traffic and more carbon emission, a conflicting issue between a transportation system and environmental concern.

Legislations Constraints - The development of transportation infrastructure is governed by the Legislation, whose responsibility is also to protect land owners' interest against conflictual use of redevelopment. LTA is consistently coping with high vehicle traffic by widening roads and expressways. The legislation requires the landowner to provide a setback within the land boundary for future road widening purpose. Although this may seem to be aligned with LTA's objective, the legislation does not allow the government to acquire the land at their convenience. It indeed protects the existing landowner that they have to forgo the setback only upon redevelopment. Therefore, land acquisition will take a longer time before any upgrading work can commence.

K. The External Factors

Population - Population growth has a great impact on land transportation system. The transportation services and infrastructure expansion need to be adequate to support the growing community. The performance metrics of sustainable transportation system are breakdown frequency, utilization rate by the commuters and travel speed.

Technology Advancement - New technology has changed the traditional way of operating transportation. The payment mode used to be coins or notes. Today, it uses debit-based payment that speeds up the payment process and reduces travelling time, improving productivity. The recent launch of vehicle sharing apps connects both vehicle operators and commuters seamlessly. In the past, taxi operators acted as third party to search for taxis on behalf, Today, technology has replaced this labour and reduce operating cost as commuters can get a private hire driver directly.

Economic outlook - In a negative economic situation, the commuter will go for a cheaper alternative transportation mode. Instead of taking a taxi, commuter may choose to take the bus. Inevitably, businesses of some constituent systems may likely be impacted too. SLTS will recalculate its budget for different transportation options based on the economic forecast.

Business competitiveness – An ongoing concern that affects the complex system. It focuses mainly on taxi companies. The launch of vehicle-sharing apps is competing aggressively with taxi companies with cheaper fare and faster response time. Taxi companies, on the other hand, are competing to employ drivers with more attractive rental rates, benefits and yet maintaining a good service quality [24].

L. Feedback Mechanism

LTA Academy was setup by LTA to conduct research studies and collect comprehensive data for using data analytics, modelling and simulation to collect comprehensive data for LTA to monitor performance, assess impact and analyse their network. Decision makers in the governing body optimize and utilize transportation infrastructure by prioritizing investments, determining trade-offs among competing demands, refining and introducing new mechanisms to influence commuters' behaviour.

One of LTA's core data analytics projects is the Planning for Land Transport Network (PLANET), where the public

transportation data analytics is built on the "journey" information, which consists of one or a series of rides by the same commuter from the origin to destination. Data mining is performed real-time by "journeys" instead of the traditionally unlinked rides. This has offered a whole new realm of opportunities to LTA to unearth the commuters' behaviour in a more meaningful way [18]. In another collaboration with A*Star in 2013, LTA performed a complex network analysis on the congestion impact upon disruption at a particular train station, simulate network recovery time using different train's dispatch time to transport commuters to their destination, identify the tipping point, critical network loads [25] and understand the emergence behaviour of commuters.

V. Impact Assessment of System of Systems

Having analysed and assessed the complex SLTS system and the problems that arose, it was a heavy payoff for the lesson learned through the series of events on the SMRT breakdown. The train operator is responsible for maintaining the entire MRT system yet due to their incompetency and lack of maintenance skill, the whole system failed frequently, causing undue stress to the overall STLS. We have learnt that the government has a great involvement in regulating the system. The absence of a governing body in auditing the maintenance system contributed to this. On the other hand, public transportation companies are accountable to their investors, hence need to maintain a profitable business by reducing operating expenses, delaying aging infrastructure replacement, leading to a conflict of interest between the governing body and public transportation companies. With this proposed system of systems governance framework, LTA can identify the need for governing bodies and manage the land transportation system more effectively and efficiently.

VI. Conclusion

In this paper, the authors have conducted a study on smart cities land transportation management and identified the major challenges faced. Based on the analysis, the authors concluded that there is a need for the proposed system of systems governance framework to be beneficial in smart cities transportation management, using Singapore as a case study to illustrate the use of this governance framework.

References

[1] Luciano, Michael, "Top 10 smartest cities in the world," ECN Mag, 2017.

[2] John Douglas Hunt and John E Abraham, "Design and Application of the PECAS Land Use Modeling System," in *International Conference on Computers in Urban Planning and Urban management*, 2003.

[3] Falconer, Shane Mitchell and Gordon, "Smart City Framework - A Systematic Process for Enabling," Cisco Internet Business Solutions Group (IBSG), September 2012.

[4] Baker, Francesca, "Machine Minds," BBC, London, 12 Dec 2018.

[5] Charles, "Telefericodemerida," 14 May 2018. [Online]. Available: http://www.telefericodemerida.com/five-countries-with-the-best-public-transportation-systems/.

[6] Rodrigue, Jean-Paul, "The Economic Importance of Transportation," in *The Geography of Transport Systems*, New York, Routledge, ISBN 978-1138669574, 2017, p. 440.

[7] Rouse, Margaret, "IOT Agenda," Tech Target Network, 2017.

[8] Clifford, Tori, "5 Urban Transportation Challenges That Big Data Can Help You Solve," Smart and Resilent Cities, America, 2017.

[9] Simperl., Elena, "The Five Challenges of IT in Smart Cities and Transport," OWD, United Kingdom, 2018.

[10] Ismail, Nick, "Intelligent transportation: The most important pillar of a smart city?," Information Age, 2018.

[11] Tan Yigitcanlar, Lawrence Fabian and Eddo Coiacetto, "Challenges to Urban Transport Sustainability and Smart Transport in a Tourist City: The Gold Coast, Australia," *The Open Transportation Journal, 2008,,* vol. 2, pp. 29-46, 2008.

[12] Hasley, Norman Akhtar and Kevin, "Smart cities face challenges and opportunities," ComputerWeekly.com, 2018.

[13] Koltovska, Mimoza Bogdanoska Jovanovska and Daniela, "Smart Cities: Transport Challenges of the Macedonian Capital City," *HOLISTICA,* vol. 8, no. 1, pp. 45-58, 2017.

[14] Julian Smith, Edward Clayton and Daniel Hanson, "Building sustainable, inclusive transportation systems," *strategyand,* pp. 5-8, 10 August 2017.

[15] National Statistical Office, "Population and Population Structure," Department of Statistics, Singapore, Singapore, 2019.

[16] Editorial, Straits Times, "Supply awaits demand on the road," Straits Times, Singapore, 2017.

[17] Sauser, Dr. John Boardman and Dr. Brian, "System of Systems – the meaning of of," in *IEEE/SMC International Conference on System of Systems Engineering*, Los Angeles, CA, 2006.

[18] Chan Heng Loon Alan, "About LTA," 2016. [Online]. Available: https://www.lta.gov.sg/content/ltaweb/en/about-lta.html.

[19] Yuen, Tan Lay, "Singapore Infopedia," National Library Board, Singapore, 1996.

[20] Committee Members, "Land Transport Master Plan," Land Transport Authority, Singapore, 2013.

[21] "Budget Report," Ministry of Finance, Singapore, 2017.

[22] Land Transport Authority, "A World Class Land Transport System," in *9971-88-488-7*, Republic of Singapore, 1996.

[23] Union of Concerned Scientists, "Why does CO2 get most of the attention when there are so many other heat-trapping gases?," Union of Concerned Scientists, Washington, DC, 2017.

[24] Siong, Olivia, "Trans-cab slashes taxi rentals amid growing competition," Channel News Asia, Singapore, 2016.

[25] IHPC Computing Science Department, "Complex Systems Modelling," A*Star, Singapore, 2013.