

The Role of Intelligent Transportation Systems in Enhancing Smart Cities: A Case Study of the Singaporean Experience

دور أنظمة النقل الذكية في تعزيز المدن الذكية: دراسة حالة التجربة السنغافورية

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Abstract

This study aims to analyze the role of Intelligent Transport Systems in enhancing Singapore’s experience as a smart city, using a descriptive-analytical approach based on official data from the Land Transport Authority (LTA) and road safety reports during the period (2009–2012–2024). The research focuses on three main dimensions: traffic flow efficiency, road safety, and environmental sustainability.

The findings show that ITS has contributed to maintaining stable average speeds on expressways and improving speeds on arterial roads despite the growth in vehicle numbers, reflecting their effectiveness in managing traffic and reducing congestion. Singapore also recorded a notable decline in accident and fatality rates, attributed to advanced monitoring and rapid-response systems. On the sustainability side, the expansion of public transport networks supported by ITS reduced reliance on private cars and lowered carbon emissions.

Keywords: Intelligent Transport Systems (ITS), Smart Cities, Traffic Flow, Road Safety, Environmental Sustainability, Singapore.

JEL Classification: R41, O33, R58 .

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ملخص

تهدف هذه الدراسة إلى تحليل دور أنظمة النقل الذكية في تعزيز تجربة سنغافورة كمدينة ذكية، بالاعتماد على المنهج الوصفي التحليلي باستخدام بيانات رسمية صادرة عن هيئة النقل البري وتقارير السلامة المرورية خلال الفترة (2009–2012–2024). يركز البحث على ثلاثة أبعاد أساسية: انسيابية المرور، السلامة المرورية، والاستدامة البيئية.

تظهر النتائج أنَّ أنظمة النقل الذكية أسهمت في استقرار متوسط السرعات على الطرق السريعة وتحسينها على الطرق الرئيسية رغم تزايد المركبات، مما يعكس فعاليتها في تنظيم الحركة وتقليل الازدحام. كما سجلت سنغافورة انخفاضاً ملحوظاً في معدلات الحوادث والوفيات المرورية، نتيجة لتطبيق أنظمة المراقبة والاستجابة الفورية. على صعيد الاستدامة، ساعد التوسع في شبكات النقل العام المدعومة بالأنظمة الذكية على تقليل الاعتماد على السيارات الخاصة، وخفض الانبعاثات الكربونية.

الكلمات المفتاحية: أنظمة النقل الذكية، المدن الذكية، انسيابية المرور، السلامة المرورية، الاستدامة البيئية، سنغافورة.

تصنيف R58، Q33، R41:JEL.

Introduction

Contemporary cities are facing growing challenges in managing traffic flow due to population growth, urban expansion, and the increasing reliance on private vehicles. In this context, Intelligent Transportation Systems (ITS) have emerged as one of the strategic solutions for enhancing the efficiency of transport networks and achieving a balance between mobility requirements, safety, and environmental sustainability. Singapore represents a pioneering model in adopting these systems within its vision of transforming into a smart city, as it has placed significant emphasis on developing digital infrastructure and implementing traffic policies supported by technological innovation. Accordingly, studying the Singaporean experience provides an in-depth understanding of the relationship between the diffusion of intelligent transportation systems and the improvement of traffic performance indicators.

Research Problem

Despite the significant advancement in smart city technologies, the relationship between intelligent transportation systems and their urban integration remains unclear in many contexts.

To what extent have intelligent transportation systems contributed to the success of the Singaporean experience as a smart city?

Sub-questions

-What is the role of intelligent transportation systems in enhancing traffic flow in Singapore?

-Do intelligent transportation systems contribute to improving road safety levels in Singapore?

-Do intelligent transportation systems support environmental sustainability in Singapore?

Research Hypotheses

Main hypothesis

H-The implementation of intelligent transportation systems constitutes a key factor in the success of Singapore's experience as a smart city.

Sub-hypotheses

H1-Intelligent transportation systems contribute to improving traffic flow in Singapore by improving traffic management.

H2-Intelligent transportation systems contribute to improving road safety by reducing accident rates.

H3-Intelligent transportation systems contribute to supporting environmental sustainability by reducing carbon emissions and improving the efficiency of transport modes in smart cities.

Importance of the Study

The importance of this study lies in providing a scientific approach to measuring the impact of intelligent transportation systems in one of the world's leading smart city models. By focusing on quantitative indicators such as trends in accident rates, average road speeds during peak hours, and daily traffic volume, the study contributes to:

- Clarifying how technology can support traffic flow and reduce accidents.
- Highlighting the role of intelligent transportation systems as a tool for achieving environmental sustainability by rationalizing the use of private vehicles and encouraging public transport.
- Providing applied results that can be utilized in formulating traffic policies for other cities seeking smart transformation.

Objectives of the Study

- Tracking the evolution of time-series data related to intelligent transportation systems in Singapore during the period (2009–2012–2024).
- Examining the impact of intelligent systems on traffic flow indicators, including average speed during peak hours and the daily volume of vehicles entering the city.
- Monitoring the extent to which these systems contribute to achieving traffic and environmental sustainability objectives.

-Providing an analytical reading of the Singaporean experience that enables the development of a framework applicable to other cities in the process of adopting smart city strategies.

Methodology

This study adopts a descriptive-analytical approach by tracking the evolution of time-series data related to intelligent transportation systems in Singapore during the periods (2009–2012–2024). The analysis relies exclusively on official data issued by relevant governmental authorities in Singapore, such as the Land Transport Authority (LTA) and road safety reports.

The analysis includes a number of key indicators reflecting the effectiveness of intelligent transportation systems in the city, namely:

- Trends in the number of traffic accidents (fatal or involving injuries).
- Average speeds on expressways and arterial roads during peak periods.
- Average daily traffic volume (Daily Traffic Volume).
- The scale and diffusion of devices used in intelligent transportation systems by type.

This data has been organized into graphs and timelines to highlight general trends. This approach aims to reveal the relationship between the spread of intelligent transportation systems and the development of efficiency, safety, and sustainability indicators in Singapore.

1. The Smart City Concept

The concept of the smart city is relatively recent and is seen as an extension of concepts such as the information city, the digital city, and the sustainable city. Its use has increased significantly since 2013. Although there is no clear consensus on a unified definition, the various definitions partially overlap without contradicting each other (Evelin Priscila Trindade et al, 2017, p. 02)The term "smart city" refers to an urban area that employs advanced technologies such as the Internet of Things, artificial intelligence, and data analytics to improve quality of life, enhance sustainability, and increase operational efficiency. This includes integrating multiple systems such as intelligent transportation, energy management, building automation, and waste

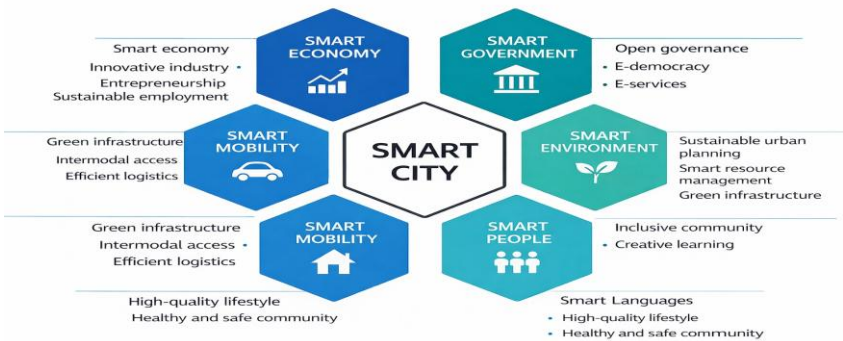
management to achieve optimal resource utilization (sciencedirect., 2025). The term consists of two parts; the term "city" refers to a large geographical area with a high population density, infrastructure, and diverse activities (transportation, healthcare, communications, etc.). "Smart" reflects the adoption of advanced technologies, systems, and policies to provide multiple benefits that extend beyond buildings and roads to include the intelligent management of services (Walid Miloud Dahmane et al, 2025, p. 05).

Thus, the concept encompasses sustainability, energy, waste management, traffic management, system integration, and the provision of health, education, transportation, and energy services. All these aspects are managed in an integrated manner to create synergy that achieves efficiency and improves quality of life. Smart cities also focus on the future by ensuring the sustainability of resources for future generations (Ana Matos et al, 2019, p. 362).

1.1.1 The six fundamental dimensions of smart cities

These dimensions are typically organized into six essential pillars that work together in an interconnected manner. This diversity contributes to strengthening the role of each pillar and producing an interactive impact that is reflected in the city's development. These pillars are key drivers for achieving the goals of smart cities and reaching sustainability, efficiency, and a high quality of life. These six dimensions include smart governance, smart economy, smart mobility, smart environment, smart people, and smart living, as illustrated in Figure 1.

Figure 1: The six fundamental dimensions of smart cities.



Source: (Fateh Belaïdet al, 2024, p. 296).

Figure 1 highlights that a smart city is built on six interconnected dimensions: smart governance, smart economy, smart transportation, smart environment, smart living, and smart people. This conceptual framework is one of the most widely adopted models in academic studies, having been introduced by Giffinger et al. in their 2007 report on the classification of medium-sized European cities and becoming a key reference in smart city research (Prince Antwi-Afari et al, 2025, p. 371).

1.1.1 Smart Governance: This is the strategic use of modern information and communication technologies to improve public decision-making, encourage citizen participation, and enhance cooperation among various stakeholders. Smart government relies on employing digital tools such as e-participation portals and open data initiatives. This contributes to increased transparency, information sharing, and citizen engagement. Smart governance is a fundamental element in building smart cities, given its requirement to manage the complex interactions between governments, citizens, and the private sector (Joel John et al, 2025, p. 07).

1.1.2 Smart Economy: The term “smart economy” refers to all initiatives aimed at improving and developing a municipal economy. A safer and more prosperous smart city attracts more talent, contributing to increased GDP and overall economic growth. Key objectives include fostering a culture of entrepreneurship and innovation, making the city a hub for startups, investors, businesses, and highly skilled new talent, and developing the economy in a creative and sustainable way that enhances competitiveness. Smart strategies and the effective use of digital technology contribute to creating a stable and beneficial environment for all stakeholders. Developing a smart economy is essential for building local and global connections, enhancing government participation in seizing opportunities, and creating supportive environments for establishing, expanding, and growing businesses, as well as generating new employment opportunities (Donatus Ebere Okonta & Vladimr Vukovic, 2024, p. 04).

1.1.3 Smart Transportation: Smart transportation provides an efficient, clean, and convenient transportation network for citizens, goods, and data. It utilizes technologies that collect and transmit information to customers, planners, managers, and supervisors, ensuring

accessible services. This includes information and communication technologies (ICTs), smart transportation networks, reforming urban transportation systems, and improving multimodal transport through coordination and organization between different modes of transport, using sustainable transportation methods. Examples include electric public buses, car sharing, car-bike integration, and the use of public transport, leading to more efficient traffic flow (Nabila Al-Ghabra, 2022, p. 05) .

1.1.4 Smart People: This refers to the qualifications and education of city residents, as well as social interactions related to integration, public life, and openness to the world. ICTs contribute to enhancing individual creativity and innovation, and increasing access to education and training (Wojciech Kozłowski & Kacper Suwar, 2021, p. 513) .

1.1.5 Smart Living: Smart living is defined as the public sphere encompassing all smart fields, applications, and tools, aiming to enhance experiences from personal, societal, environmental, and institutional perspectives. It can be considered the societal sphere that unites initiatives based on the use of smart tools and applications in diverse environments (Elena Kornyshova et al, 2025, p. 13) .

1.1.6 Smart Environment: A smart environment refers to the natural conditions of urban living (such as green spaces), pollution, resource management (such as resource reuse and replacement), and environmental protection. Solutions that demonstrate a smart environment include, for example, effective waste management, the use of renewable energy sources, and green urban planning. Information and communication technologies are used to improve the urban environment (Wojciech Kozłowski & Kacper Suwar, 2021) .

2. Concept of Intelligent Transportation Systems (ITS):

An Intelligent Transportation System (ITS) is defined as a technology-based system that uses computer connectivity and collaboration to manage traffic flow. It aims to reduce congestion, enhance sustainability, and improve crisis response through the use of Internet of Things (IoT) devices such as sensors (sciencedirect, Intelligent Transportation System, 2025). ITS employs a wide range of technologies to monitor, evaluate, and manage transportation systems with the

goal of enhancing efficiency and safety. These systems comprise a broad spectrum of technologies, including electronics, information processing, wireless communications, and control systems, and are designed to improve overall safety, efficiency, and ease of use within the road transportation network (A. H. M. Mehbub Anwar & Abu Toasin Oakil, 2024)

2.1. Core of Intelligent Transportation Systems:

Intelligent Transportation Systems (ITS) are a combination of hardware and software that collect data from multiple sources, such as traffic signals, cameras, and vehicle sensors. This data is then processed and analyzed to make immediate decisions or provide strategic insights for improving traffic management and transportation planning. These systems rely on communication between vehicles and infrastructure, ranging from simple interactions to complex networks that include autonomous vehicles (digi, 2025). This is illustrated in Figure 2, where all steps occur in real time.

Figure 2: Core of Intelligent Transportation Systems.

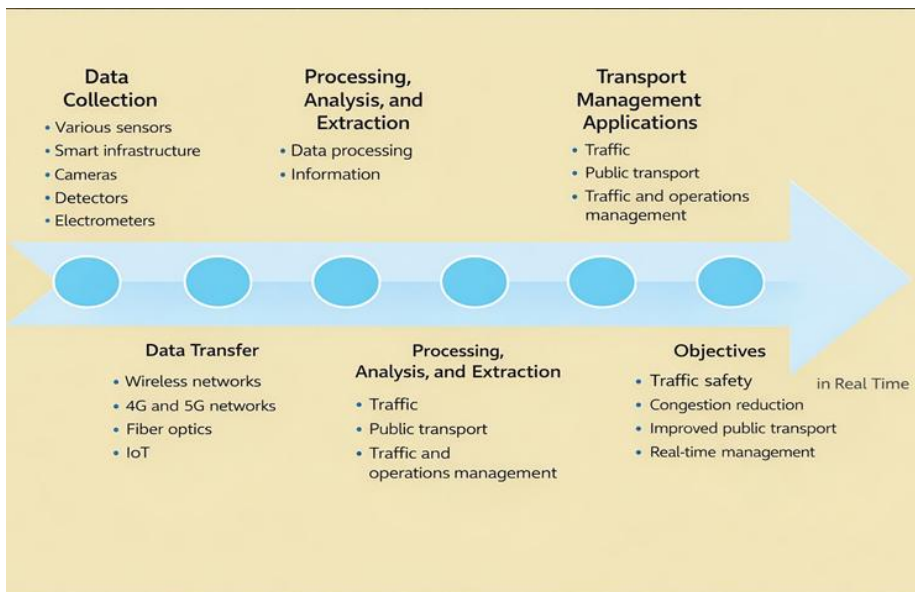


Figure 2. Source: Authors' own elaboration.

2.2. Intelligent Transportation Systems (ITS) Technologies

2.2.1 Intelligent Transportation Systems Data Processing, Management, and Archiving Technologies: These are a set of technologies and systems used to collect, store, organize, analyze, and archive transportation data from various sources to support decision-making, planning, operations, and simulation (piarc, 2025) .

2.2.2. Detection Technologies: These are a set of technologies and devices used to monitor and track vehicles, pedestrians, and road conditions to collect accurate traffic data. These technologies include sensors integrated into or mounted above/beside the road and are used in applications such as signal control, speed measurement, accident detection, and traffic management.

2.2.3 Communication Technologies: Communication technologies are the digital infrastructure that transmits data, commands, and information between the components of Intelligent Transportation Systems (ITS). This includes wired communications such as fiber optic cables, Digital Subscriber Line (DSL), and cable internet; wireless communications such as Wi-Fi, cellular networks, and radio waves; and leased systems (renting existing infrastructure from telecommunications service providers).

2.2.4 Information Dissemination Technologies: These refer to the tools and systems used to deliver traffic and travel data to users. These technologies rely on real-time and historical data, collected and processed from multiple sources, and presented through diverse user interfaces to support informed decisions regarding route selection, mode of travel, and departure time (sciencedirect, Information Dissemination, 2025) . They include Dynamic Message Signs (DMS), Highway Advisory Radio (HAR), mobile applications, smart devices, in-vehicle systems, websites, helplines, cable television, and kiosks (UNIVERSITY OF NORTH TEXAS, 2025).

2.2.5 Traffic Control and Vehicle Control Technologies: These technologies are used to monitor, manage, and regulate vehicle movement and traffic flow in real time. They consist of traffic signals and adaptive signal control, ramp entry and lane control systems, automatic accident detection, and integrated vehicle guidance and control systems.

2.2.6 Electronic Payment Technologies: Electronic payment technologies are a set of smart systems that enable automatic payment of transportation fees without the need for cash. These include smart cards, radio-frequency identification (RFID) transmitters, smartphones, and navigation systems (GNSS and DSRC). These systems operate through front-end user interfaces and back-end processing systems, aiming to expedite payments, reduce costs, and improve the travel experience (Mahir Shahrier et al, 2024, pp. 968-969).

2.2.7 Monitoring and Enforcement Technologies: These are the technologies used in Intelligent Transportation Systems (ITS) to monitor, detect, and automatically enforce traffic laws. These systems improve road safety, reduce violations, and ensure compliance. Many other automated enforcement technologies are used effectively in addition to speed and red-light cameras, including:

2.2.8 Automatic License Plate Recognition (ANPR): To support a range of law enforcement tasks, such as tracking stolen vehicles, monitoring vehicle tax compliance, and managing toll collection, ANPR systems capture and analyze vehicle license plate numbers in real time. These systems are frequently added to traffic law and speed limit enforcement systems.

2.2.9. Mobile traffic cameras: These cameras can be quickly deployed in various locations, focusing on areas with high traffic violation rates. Without requiring permanent installations, they help maintain a clear view for relevant authorities.

2.2.10. Drones and aerial surveillance: Drones offer a flexible solution for areas difficult to monitor using traditional methods. Equipped with cameras, they can monitor traffic violations and patterns from the air.

2.2.11. Traffic violation detection systems: These systems can detect traffic violations, such as not wearing a seatbelt or using a mobile phone while driving. They utilize advanced image recognition technology to capture and analyze driver behavior in real time (Alobaidallah, A.M. & Maniruzzaman, K.M., 2025, p. 03).

2.3 Intelligent Transportation Systems (ITS) applications: This term refers to the application areas of Intelligent Transportation Systems in transportation management, or in other words, the eight main service areas of Intelligent Transportation Systems where these systems are implemented. These include:

2.3.1- Traffic and Road Management: This is the process of monitoring and controlling traffic flow on roads, highways, and other transportation systems to ensure the safe and efficient movement of vehicles and pedestrians. It includes traffic monitoring, signal timing, road construction and maintenance, parking management, and incident response. Traffic management is crucial for alleviating congestion, improving safety, and enhancing the overall transportation experience for all road users. It involves a combination of technology, planning, and implementation to optimize traffic flow and reduce delays (Rob Paredes, 2025) .

2.3.2 Public Transit Systems: Advanced Public Transit Systems (APTS) applications are designed to improve the efficiency and ease of use of public transportation services. They include enhanced information systems for publishing timetables and fares and sharing information more conveniently to users online and through other media; automated fare collection systems, which eliminate the need for precise change; and vehicle location systems to improve fleet management, increase security, and communicate with passengers when the next bus is arriving (Praveen Kumar & Sanjeev Suman, 2029) .

3. Applied Framework

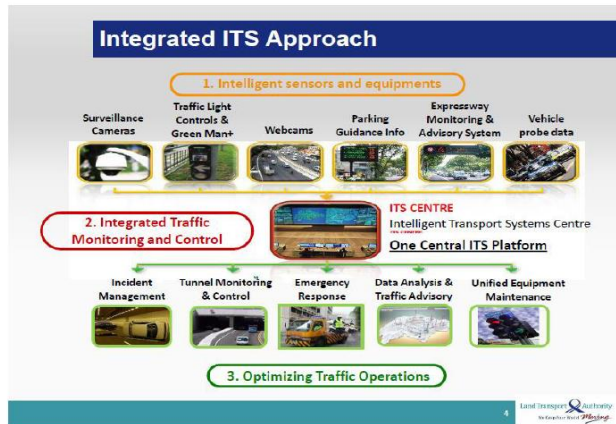
3.1. Presentation and Analysis of Intelligent Transportation Systems in Singapore

3.1.1. Definition of Intelligent Transportation Systems in Singapore: The Land Transport Authority of Singapore (LTA) defines Intelligent Transportation Systems (ITS) as an integrated network of devices, sensors, cameras, and control systems that collect and analyze traffic data, travel times, and road requirements across the island. This aims to create a real-time and dynamic picture of daily commuting, thereby enhancing road network efficiency, supporting traffic management, and contributing to safer and more efficient mobility (LTA, 2025).

3.1.2. Approach to Intelligent Transportation Systems in Singapore

Figure 3 presents an integrated approach to Intelligent Transportation Systems (ITS) in Singapore through a sequential presentation of the components and functions of these systems. This approach is based on three main phases:

Figure 3. Integrated Intelligent Transportation Systems (ITS) Approach in Singapore.



Source: (Chin Kian Keong; Land Transport Authority of Singapore, 2019, p. 04).

3.1.2.1 Sensors and Smart Equipment: The diagram refers to the technological infrastructure that forms the basis for collecting traffic data, such as surveillance cameras, webcams, traffic signal control systems, parking guidance systems, as well as highway systems and electronic signage. These tools represent the first layer (Layer of Sensing & Data Collection), responsible for monitoring vehicle flow, recording violations, and providing accurate, real-time data.

3.1.2.2 Integrated Traffic Monitoring and Control: At this stage, the pivotal role of the traffic control center becomes apparent. It utilizes a unified central platform to connect various intelligent transportation systems. Functions such as incident management, tunnel monitoring and control, emergency response, and data analysis for congestion prediction are highlighted here. This reflects the second layer (Layer of Processing & Decision-Making), where raw data is transformed into actionable information for decision-making.

3.1.2.3 Improving Traffic Operations: This represents the system's ultimate goal: to move from data collection and real-time control to achieving smoother traffic flow, reducing accidents, improving emergency response, and enhancing road safety. Here we find the integration of technology and operational structure in the service of managing transport demand and improving operational efficiency.

3.1.3 Components of Intelligent Transportation Systems in Singapore iTransport: The iTransport system forms the core of the Intelligent Transportation Systems. All ITS data is connected to it. It is an integrated and unified platform that analyzes data to monitor traffic flow and distributes information for incident management at the ITS Operations Control Centre. iTransport is a large-scale, intelligent backhaul system that fully integrates existing ITS systems and can be expanded to include new ones. iTransport also has the ability to integrate raw traffic data collected from ground sensors and transform it into relevant traffic information used for traffic analysis and planning, and for developing more informed transport policies (Land T transport Authority, 2025) .

3.1.3.1 Intelligent Transportation Systems Operations Control Centre (OCC): Operates 24/7 to monitor traffic flow and ensure its smooth movement across the iTransport system and various ITS systems. It monitors traffic, manages incidents on highways and in tunnels, and deploys rescue teams and traffic controllers in coordination with the Singapore Police Force and Civil Defence to respond quickly to emergencies. The center also provides the public with real-time information to support travel decisions, including:

- Traffic messages and journey time estimates via EMAS signs on highways and arterial roads.
- Data on accidents, road closures, maintenance work, and recommended speed limits.
- Information via the OneMotoring platform, the MyTransport.SG app, and the @LTATrafficNews Twitter account.
- Webcam images from strategic locations.

3.1.3.2 Highway Monitoring and Advisory System (EMAS): This is an intelligent incident management tool that manages traffic along our highways. EMAS detects accidents, vehicle breakdowns, and incidents instantly through a network of cameras operated by the LTA Operations Center, ensuring rapid responses to restore normal traffic flow. It also provides real-time traffic and travel time information on electronic signs located before and along highways. Traffic information is also disseminated through OneMotoring, the MyTransport.SG mobile app, @LTATrafficNews on Twitter, and radio stations (Cheang, Chee Yew, Goh, Lee Kim, 2025) .

3.1.3.3 Green Link Identification System (GLIDE): The Green Link Identification System (GLIDE) controls all traffic lights in Singapore by adjusting the green light timing as traffic flow changes. GLIDE also links adjacent traffic lights to allow vehicles to move from one intersection to another with minimal stops. Loop detectors are used to detect the presence of vehicle traffic and adjust traffic lights in order to:

- Allocate green time for motorists and pedestrians on demand;
- Provide a "green wave" link between adjacent intersections to reduce the number of stops made by vehicles;
- Allow for the rapid correction of traffic light errors (LTA, 2025).

3.1.3.4. Green Man+ system : The Land Transport Authority of Singapore (LTA) defines the Green Man+ system as an intelligent traffic signal system that aims to facilitate the crossing of elderly (60 years and over) and disabled pedestrians, by extending the green crossing signal time by an additional 3 to 13 seconds, by swiping the designated CEPAS cards on the reader device installed at the signal pole. More than 1,000 pedestrian crossings across the island have been equipped with this technology, with plans to expand to 1,500 crossings by 2027. (Aljunied-Hougang Town Council, 2025).

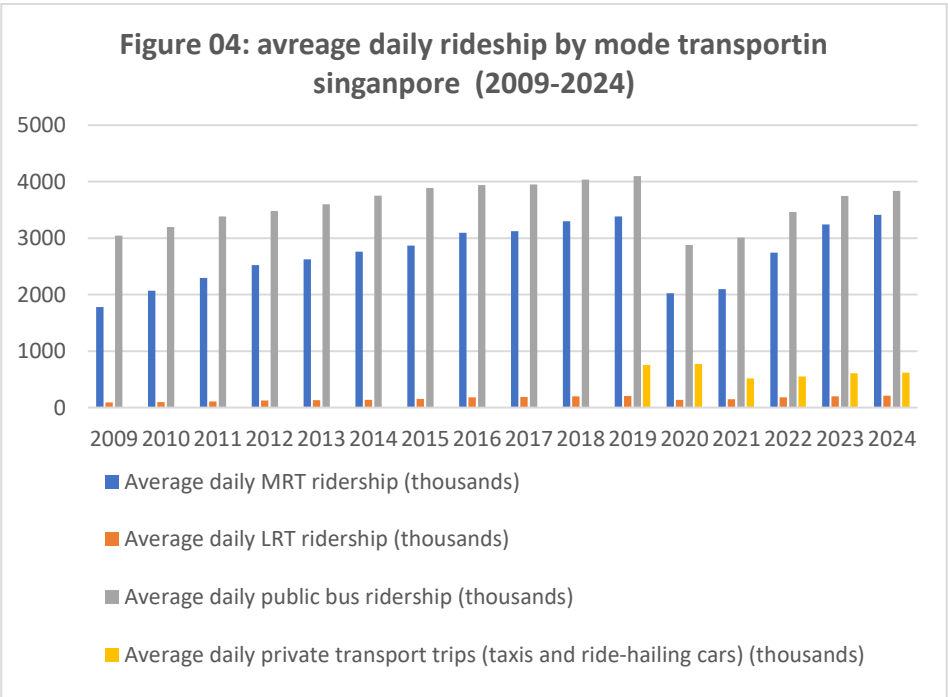
3.1.3.5. Parking Guidance System: The Parking Guidance System (PGS) provides updates on available parking spaces via 28 electronic roadside information boards, which are easily visible even while driving. This real-time information helps reduce haphazard traffic caused by searching for available parking spaces in the central business district and along major

commercial streets. The system also enables drivers to make more informed parking decisions and helps improve the utilization of available parking spaces. It is available via various digital platforms (GOVTECHSINGAPORE, 2025).

3.1.3.6. TrafficScan System: TrafficScan is a transportation system that uses GPS data from taxis to calculate average traffic speeds on roads. This real-time information is then provided to drivers to help them plan their routes and ensure a smoother journey (Land T transport Authority, 2025).

3.1.4 Analysis and discussion of the role of intelligent transportation systems in Singapore

3.1.4.1 Evolution of Transport Mode Distribution in Singapore: Based on Figure 4, we can observe changes in the distribution of different transport modes in Singapore.



Source: Prepared by the authors based on available data: (Singapore Department of Statistics, 2025).

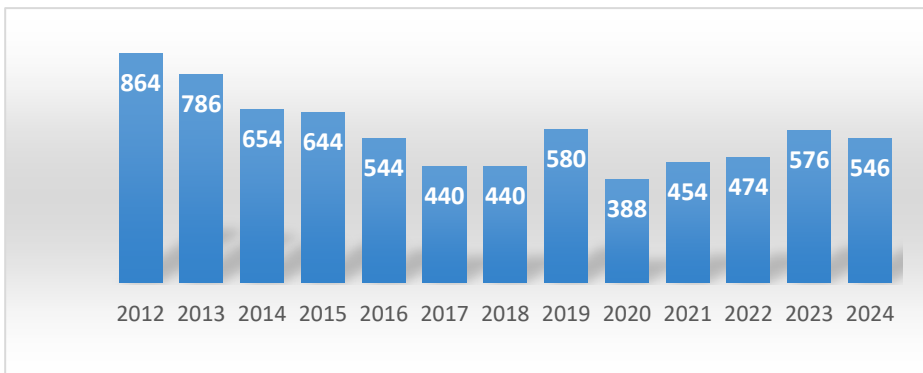
Data from Singapore shows that intelligent transportation systems (ITS) have made a significant contribution to environmental sustainability by improving the efficiency of commuting patterns. The length of the metro network increased from 67 kilometers in 1990 to over 242 kilometers in 2024, which in turn led to a rise in the average daily number of metro passengers from approximately 740,000 to 3.4 million during the same period. This expansion, supported by intelligent train operation and scheduling systems, has reduced reliance on private cars and individual transportation, leading to lower carbon emissions and reduced traffic congestion. The bus network has also maintained high ridership rates (around 3.8 to 4 million passengers daily), while point-to-point transportation has remained relatively limited, reflecting the success of smart policies and systems in making public transportation more attractive and efficient. Therefore, the

Singaporean experience confirms that ITS not only improves traffic flow but also serves as a key tool for achieving environmental goals and urban sustainability.

3.1.4.2 Evolution of Fatal Accidents and Accident-Related Deaths in Singapore

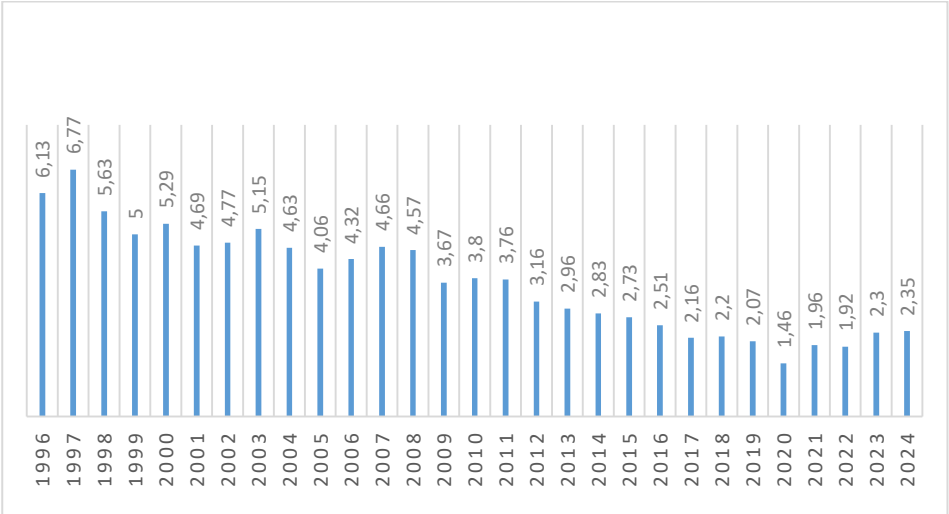
Figures 5 and 6 illustrate the trends in fatal accidents and transport-related mortality in Singapore over time. Figure 5 presents the total number of fatal accidents, while Figure 6 shows the transport accident mortality rate (per 100,000 population).

Figure 5. Total number of fatal accidents in Singapore.



Source: Prepared by the authors based on available data: (Singapore Department of Statistics, 2025).

Figure 06: Transport Accident Mortality Rate (per 100,000 population) in Singapore.



Source: Prepared by the authors based on available data: (Singapore Department of Statistics, 2025).

Data shows a general trend of gradual decline in fatal traffic accidents in Singapore between 2012 and 2024, dropping from 864 fatal accidents in 2012 to 546 in 2024. The traffic fatality rate also decreased from 6.13 to 2.35 per 100,000 people between 1996 and 2024, decreased by more than 50%. This decline is a positive indicator of the effectiveness of the traffic policies and intelligent transportation systems adopted by the country since the establishment of the Land Transport Authority.

The activation of intelligent transportation systems in Singapore, which have undergone continuous updates in terms of equipment and technology over time, such as the EMAS system, established in 1986 to monitor traffic flow on highways using surveillance cameras, and the J-Eyes intersection system, which covered all highways in 1993, contribute to the early detection of malfunctions, obstacles, and accidents, enabling immediate response and thus enhancing road safety. The Green Man+ system, launched in 2009, contributes to reducing accidents and increasing road safety. It is projected that 2,700 lanes will be equipped with the system by 2027. Similarly, the Glide system, which utilizes advanced technologies to optimize traffic signal timing based on real-time conditions, manages 2,700 intersections across Singapore, making it one of

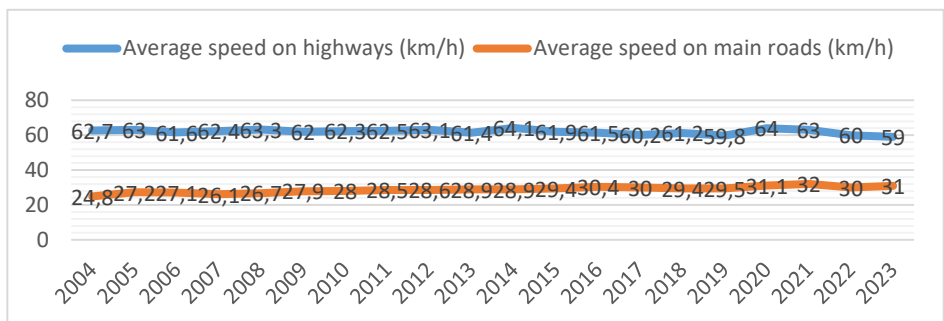
the most comprehensive road safety systems globally. This system prioritizes emergency vehicles and efficiently manages crossings. Various transportation systems that disseminate real-time traffic information via electronic displays and smartphone applications available to drivers also contribute to reducing the likelihood of accidents through early warning. Furthermore, the gradual shift towards safer public transportation systems (MRT, LRT, and buses) has reduced the population's reliance on private cars, resulting in a relative decrease in accidents.

With the exception of 2020, which saw a significant decrease in the number of accidents and the resulting fatalities—the lowest levels during the period—this is attributed to the mobility restrictions imposed during the COVID-19 pandemic. This reflects a circumstantial effect not directly related to policies and intelligent transportation systems. The overall trend indicates the success of road safety strategies, but the fluctuations between some years (such as the rise in 2019 followed by a sharp decline in 2020) show that accidents are also influenced by external factors such as economic activity or traffic volume.

Despite the decrease, the figures still indicate that the human element (negligence, loss of control, reckless driving) remains a major factor, necessitating a focus on strengthening awareness programs alongside technological solutions.

3.The evolution of distances traveled on Singapore's roads during peak hours: Figure 7 shows the evolution of vehicle distances traveled in Singapore on major roads and expressways

Figure 7. Average Traffic Speed During Peak Hours in Singapore.



Source: Prepared by the authors based on available data: (Singapore Department of Statistics, 2025).

Figure 7 illustrates the evolution of average speed on Singapore's main roads and expressways during peak hours for the period 2004–2023. It shows that average speed on expressways remained relatively stable at 62–64 km/h despite the continuous increase in the number of vehicles, while average speed on main roads gradually improved from 25 km/h in 2004 to 31 km/h in 2023. This stability and relative improvement reflect the positive impact of implementing Intelligent Transportation Systems (ITS), which helped regulate traffic flow and reduce congestion, particularly through signal control and peak-hour traffic management systems. Therefore, the results support the hypothesis that ITS contributes to smoother traffic flow in Singapore.

4. Discussion of Results: The results obtained from the time-series data analysis for Singapore during the period 2009–2024 demonstrate that the implementation of ITS has had a significant impact on various dimensions of traffic performance in the city.

First, regarding the smoothness hypothesis, data indicates that average speed on highways remained relatively stable (62–64 km/h), while speed on main roads improved from 25 km/h in 2004 to 31 km/h in 2023. This reflects the ability of traffic control systems (GLIDE, EMAS, and real-time information systems) to mitigate traffic congestion. This confirms that intelligent systems not only prevented the decline in traffic service levels with the increasing number of vehicles but also contributed to improved traffic flow.

Secondly, regarding the safety hypothesis, data showed a steady decrease in the number of fatal accidents from 864 in 2012 to 546 in 2024. The death rate per 100,000 inhabitants also decreased from 6.13 in 1996 to 2.35 in 2024. This improvement is linked to the integration of intelligent monitoring and rapid response systems (such as J-Eyes and incident management systems), as well as smart solutions for managing traffic intersections and pedestrian crossings (Green Man+). Despite some fluctuations between years, the overall trend remains a clear indicator of the strategy's effectiveness. However, the need to accompany technological solutions with awareness programs targeting human behavior, as it is one of the main factors behind accidents, is evident.

Third, regarding the sustainability hypothesis, the significant expansion of public transport networks (from 67 km of metro lines in 1990 to over 242 km in 2024) and the increase in metro ridership to 3.4 million passengers daily indicate Singapore's success in encouraging the shift from private cars to public transport. This is supported by the maintenance of high bus usage levels (3.8–4 million passengers daily), while individual transport (taxis and private rental cars) remains relatively limited. This means that intelligent transport systems have contributed to reducing carbon emissions and achieving one of the most important dimensions of environmental sustainability.

Therefore, the main hypothesis, "intelligent transport systems are a pivotal factor in the success of Singapore's smart city experience," is confirmed, as the data demonstrates that these systems do not operate in isolation, but rather within an integrated policy framework that combines digital infrastructure, effective governance, and incentives for the use of sustainable transport.

A detailed analysis of the results shows that the effectiveness of intelligent transportation systems (ITS) in Singapore extends beyond isolated performance improvements, reflecting a fundamental shift in urban mobility management. The stability of highway speeds, despite continued growth in vehicle ownership, indicates the success of ITS in decoupling traffic performance from demand a crucial achievement in densely populated cities.

This success is attributed to the integration of predictive traffic management tools, real-time monitoring systems, and adaptive traffic signal control mechanisms. These technologies enable proactive rather than reactive traffic management, allowing authorities to anticipate traffic congestion patterns and implement corrective measures in advance.

Furthermore, the significant improvement in speeds on major roads highlights the role of local ITS applications, particularly systems like GLIDE, which enhance intersection performance. This demonstrates that micro-level traffic interventions can have a substantial macro-level impact on the efficiency of the traffic network.

Regarding road safety, the continued decline in fatal accidents reflects the combined impact of enforcement technologies, behavior monitoring, and rapid incident response systems. This

indicates that intelligent transportation systems (ITS) not only contribute to reducing accidents but also mitigate their impact through rapid intervention in emergencies.

From a sustainability perspective, the shift towards public transportation is not merely a result of infrastructure expansion but also a consequence of the improved service reliability and user information systems provided by ITS. Real-time travel information, integrated ticketing systems, and efficient scheduling systems increase user confidence in public transportation, influencing their travel behavior.

Overall, these findings confirm that ITS functions as a supporting infrastructure that enhances the effectiveness of comprehensive urban transport policies, rather than being a standalone technological solution.

5. Conclusion

This study concluded that intelligent transportation systems (ITS) are a cornerstone of Singapore's success as a smart city, as their implementation has had a positive impact on three key dimensions:

- Traffic flow: by improving vehicle movement and maintaining stable speeds during peak hours.

- Traffic safety: by reducing accident and fatality rates through monitoring and early response systems.

- Environmental sustainability: by reducing reliance on private cars and increasing the appeal of public transportation, thereby lowering emissions and enhancing the efficiency of commuting patterns.

The experience demonstrates that the success of ITS is not solely dependent on technology adoption, but also on its integration with public policies, the development of a sustainable public transportation culture, and citizen engagement in utilizing smart solutions. The findings also indicate that Singapore has established a globally exemplary model for urban transport

management, which can serve as a reference for countries and cities striving to transform into safer and more sustainable smart cities.

Study Prospects and Challenges

Despite the significant achievements demonstrated by the Singaporean experience in implementing Intelligent Transportation Systems (ITS), several challenges remain that may affect the scalability and transferability of this model to other contexts.

- the high cost of implementing and maintaining ITS infrastructure represents a major barrier, particularly for developing countries. These systems require substantial investments in digital infrastructure, sensors, communication networks, and data management platforms.

- Security challenges: Intelligent Transportation Systems (ITS) are exposed to cyber attack risks due to their reliance on connected technologies such as Vehicular Ad-Hoc Networks (VANETs) and Internet of Things (IoT) devices.

- Operational challenges: These relate to system reliability, as software errors or system failures can lead to serious traffic disruptions.

- Developing countries, in particular, may face several major obstacles to the deployment of intelligent transportation systems (ITS), including financial constraints, lengthy implementation periods, unreliable energy supplies, weak internet and communications infrastructure, and socio-cultural barriers such as illiteracy, lack of trust in technology, and a shortage of technical skills. These factors collectively slow the adoption of ITS solutions and reduce their effectiveness.

In terms of future prospects, the integration of Artificial Intelligence (AI) and machine learning into ITS is expected to further enhance predictive capabilities and optimize traffic management systems. Additionally, the development of autonomous vehicles and vehicle-to-infrastructure (V2I) communication technologies will play a key role in shaping the next generation of smart mobility.

Future research could focus on comparative studies between developed and developing cities to assess the adaptability of ITS models under different economic and institutional conditions.

It is also recommended to explore the environmental impact of ITS using more precise indicators, such as real-time emission measurements.

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