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Green transportation for sustainability: Review of current barriers, strategies, and innovative technologies

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ABSTRACT

The sustainability of a transportation system is a major concerning factor for urbanisation, as evidenced by the ever-growing problems of air pollution issues in major cities. While the growing population and migration don't have too much control to overcome the widespread use of public and personalised vehicles, it has destroyed our global environment. Therefore, the expansion of the transportation system should be carefully planned for global sustainability: so-called green transportation or sustainable transportation. In this paper, factors that should be considered when implementing green transportation for global sustainability have been critically reviewed. Firstly, barriers and challenges associated with current travel demands and blocking the implementation of green transportation have been identified. A three-step strategy (so-called ASI strategy, *i.e.*, avoid, shift, and improve strategy), which had been proposed to overcome the challenges and barriers, was investigated. Identification of innovative technologies or management approaches has been proposed for greening the public transportation system. Finally, some well-recognised success stories of the ASI strategy were presented, in which Avoid can reduce 146–312 kg_{CO2}/y, Shift can be reduced 0.27 kg_{CO2}/revolution of vehicles use and Improve can be reduced 12.4% CO_2 emissions. This review guides successful urban planning through the green transportation system.

1. Introduction

Due to the rapid urbanisation over the past decades, the ratio of the global population living in urban areas increased from 34% in 1960 to 56% in 2019 (UN, 2018). The urban population is projected to reach 5.0 $\times 10^9$ against 8.2 $\times 10^9$ total global population by 2050 (Fig. 1). At the same time, the economic structure has been shifted: observed with the declining gross domestic product (GDP) of agriculture from 27% to 10% and the growing GDP of the industry from 32% to 43% due to the increased demand for urbanisation (Roser, 2017). With increasing population and economic size and the high demand of the younger generation for a personalised vehicle, the total number of registered vehicles has increased from 200 M (in 1960) to 1431 M worldwide (in 2018) (Davis and Boundy, 2020). There are currently 1.42 billion (10^9) cars in use worldwide, including 1.06 billion (10^9) cars and 363 M (10^6) commercial vehicles. For comparison: in the year 2009, the number of cars worldwide reached 1 billion (OICA, 2021). According to the International Energy Agencies (IEA) Global EV Outlook, the number of electric cars on the roads around the world, including battery electric vehicles and plug-in hybrid electric vehicles, reached 2 M in 2016 (Deloitte, 2021). To study the evaluation of vehicle types with population growth, it is essential to understand the history and trend of the transportation systems. In 3500 BCE, the first wooden wheel was invented (Gambino, 2009). The modification of wheel technology in the form of chariots was introduced in 2000 BCE (Rossi et al., 2016). European people developed horse-drawn coaches in the 1400's (Transport Wagons, 2020). They developed oceangoing transport in the same era. Following a considerable convention in the water-based transportation system such as wooden ships, the steam engine was developed as the most effective mode of transportation (Nguyen, 2020). Not only by sea and road but air transport was developed in the year 1783 in the form of an air balloon (BBML, 2017). Independent transportation through

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personalised vehicles such as bicycles was developed in 1790 (Bellis, 2020). The first motor car was invented in 1886 (TimePat, 2012). The more advanced version of the automobile, i.e. the autonomous car, was first invented in 1980 (Reilly, 2016). Global population and vehicle use indicate that several million vehicles were used and that there were more people in rural areas than in urban areas (Dargay et al., 2007). In present era of urbanisation, the transportation system has improved in the form of integrated public transportation technologies such a maglev train (1984), electric-subway railing (1890), engine-powered aircraft (1903), cruise ships (2002), and electric vehicles, as well as personal-rapid-transit service (2010) (Timeline, 2021) (See Fig. 1). The development of personalised vehicle types led to massive traffic on the roads and created major mobility problems. Logistics is the heart of modern transportation (Fan et al., 2018a), as a dependency on freight transportation is equally weighted in the same way as public transportation (Touratier-Muller et al., 2019). The present transportation planning aims to enable people to commute to their daily activities, make freight transportation more energy-efficient, while at the same time mitigating the negative impact of transportation on the climate, the environment, and human health (Sun et al., 2019). Simultaneously, sustainable development is defined as meeting current needs without affecting future needs (Brundtland, 1987). From the same context, sustainable transportation can be defined as the ability to meet the mobility needs of today's society in such a way that the environment is least polluted and the mobility needs of the next generation are not impaired.

Sustainable transportation should contribute to achieving the sustainable development goals first set at the 1992 Earth Summit and reaffirmed at the United Nations Conference on Sustainable Development in 2012 (Li et al., 2015). In order to improve transportation sustainability, several countries and regions have developed tools, policies, and action plans to focus the decision on transportation-related matters (Schiller and Kenworthy, 2003). However, the current state of public transit service is considered unsustainable due to the extensive use of the fossil fuels driven transportation system, including private vehicles, which is more concerning the emission of CO_2, CO, volatile organic compounds (toxic air pollutants, e.g., benzene, formaldehyde, cyanide dioxide, etc.), oxides of nitrogen and sulfur, and also fine particulates matters (including caron black, heavy metals, micro and nano plastics) (Fan et al., 2018b). The emissions of CO_2, SOx and particulate matter (PM_{10} and $PM_{2.5}$) in major cities are listed in Table 1. In particular, PM_{10} and $PM_{2.5}$ emissions occur because of incomplete combustion of fuels and wear of brakes and tires. All emitted gases are responsible for various health problems such as cardiac arrhythmias, heart attacks, and severe asthma attacks.

Table 1
Air quality indexes and GHG emissions in selected cities (in 2021) (AQI, 2021).

Region		PM_{10}	$PM_{2.5}$	SO_2	NO_2	GHG (t_{CO2e}/cap)[a]
	Durban	56	95	6	11	
Africa	Johannesburg	35	76	22	12	9.92
	Cape Town	65	48	4	13	7.6
South-America	Sao Paulo	59	134	1	15	1.4
	Mexico-City	131	190	34	35	5.53
North America	New York		58		46	
		55	80	2	37	
Eastern	Abu Dhabi	77	99	6	36	
Mediterranean	Cairo	284	117			
Europe	London	25	60	9	31	9.6
	Berlin	45			30	
South-East Asia	Delhi	240	243	14	35	1.5
	Kolkata	138	197	33	9	1.1
	Dhaka	104	240			
	Mumbai	155	117	19	41	1.2
Western Pacific	Shanghai	60	102	17	49	12.9
	Beijing	86	149	22	34	10.8
	Seoul	55	107	7	71	4.1
	Sydney	17	66	8	20	20.3[b]
	Sydney	17	66	8	20	20.3[b]

Note: PM_{10} represents PM of 10 μm or less. a (WB, 2011); b (Levitz, 2017).

The current emission values presented in Table 1 are not limited to greenhouse gases (GHG), but they also include the other pollutants, and the upcoming system with the lowest GHG emissions may not solve the potential environmental problems without considering other pollutants (Fan et al., 2019). That is why the adaptation to the electrification of the vehicle is now picking up speed; electric vehicles have a great potential for solving climate issues by limiting CO_2 emissions. However, the International Energy Agency (IEA) has also decided to limit CO_2 emissions in its World Energy Outlook 2016 to 60g CO_2/kg in OECD countries and 85g CO_2/kg in non-OECD countries (IEA, 2016). The search for alternative fuels for the transport system would be an alternative option (Raymand et al., 2021). However, an economic impact needs to be considered beyond the environmental strain (Kapeller et al., 2021). In most cases, existing infrastructures and engineering systems have to be changed from the beginning.

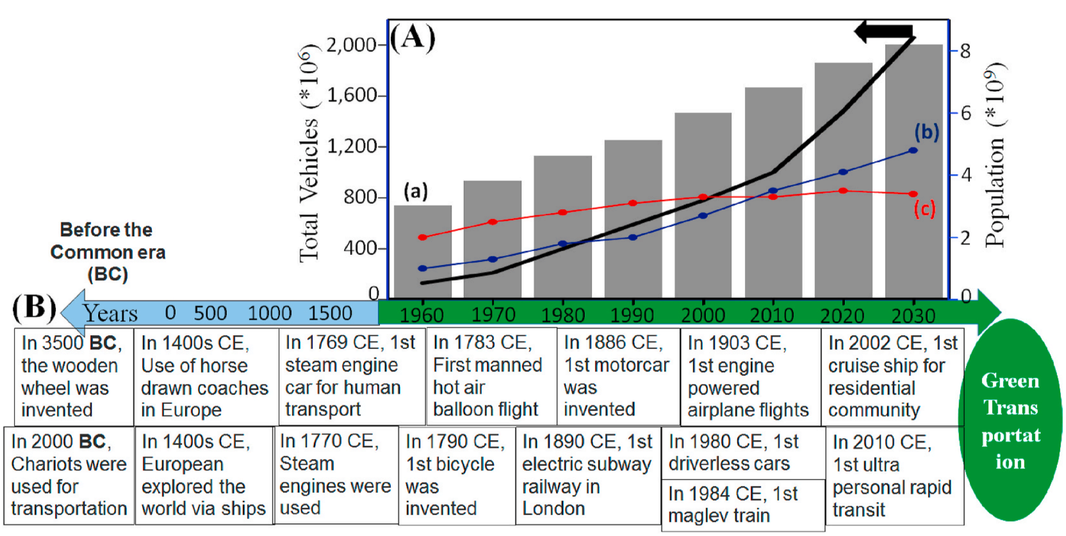

Fig. 1. (A) The growth of total vehicles (black line) against world population growth ((a) total (column), (b) urban (blue line), and (c) rural (red line)); (B) Transportation history.

1.1. Overview of the recent development of the mobility problem in urban cities

To tackle the mobility-related problem, UN Secretary-General Ban-Ki-moon set up the High Level Advisory Group on Sustainable Transport to develop recommendations on how to deal with increasing over-crowding and pollution in urban cities (UNSG, 2016). The Group Sustainable Transport Report was published in Mobilizing Sustainable Transport for Development, published at the first global conference on sustainable transport in 2016. However, according to the UN Sustainability Report 2020, only half of urban cities have convenient access to public transport (WCR, 2020). Therefore, the development of informal transportation systems, which often lack security features, has increased. In the meantime, the new terminology Mobility as a Service (MaaS) is often suggested as an instrument for achieving sustainable mobility, in particular for increasing the proportion of public transport in cities. A search in Scopus with the term "Mobility as a Service" resulted to 500 article in the year 2020 (Santos and Nikolaev, 2021). Despite the significant work that has been done, there is still some ambiguity about the concept of sustainable mobility. Moreover, the COVID-19 pandemic has had a huge impact on travel behaviour in most parts of the world and have huge impact on entire economy (Sung and Monschauer, 2021). All modes of transport are affected by the crisis, from private vehicles and public transport in cities to buses, trains and planes around the world. This is the time when we need to take into account economic and technological advances in order to strengthen the transport system. After considering the gravity of the problem associated with the entire transportation system, researchers urgently need to elucidate the system and define green transportation (GT). In this study, we first review the traditional transport system and its issue associated with air pollution. In addition, we identify barriers or challenges that should be addressed to transform the traditional transport system into a GT. The authors reviewed currently available strategies, including innovative technologies and management, approaches, for establishing a GT and also illustrated the outcomes of the implementation of those strategies to strengthen the transportation system.

1.2. Definition of GT

Transportation has a significant economic, social, and environmental impact on society (Fig. 2). Transportation should be given priority to achieve sustainability goals in urban areas; the latter can be achieved by managing the diverse aspects of travel demand (public transportation), vehicle growth patterns, and efficient land-use patterns (Sangaradasse and Eswari, 2019). Green transportation can be defined as "the transportation service with a fewer negative impact on human health and the environment compared to existing transportation services" (Björklund, 2011). GT can be considered as a combinatorial technology comprising of the optimal use of traditional fuels, the efficient use of electric vehicle technologies, the use of biogas as a fuel for buses and strengthened public transportation (Lee et al., 2017). An effective GT system can lead to.

- Reduced risk
- Reduced traffic congestion
- Enhanced energy and resource sustainability
- Reduced pollution and accident prevention
- Increased safety and security assurance
- Optimised travelling speed and traffic flow

1.3. Objectives of international agreements and policies related to transportation systems

Several agreements and policies have been implemented in recent years to achieve the goal of being eco-friendly, economically viable, and building the welfare of society (UNFCCC, 2015). The Paris Agreement (4 Nov 2016) was implemented to control the earth's temperature against a climatic threat by keeping a global temperature rise below 2 °C (NRDC, 2017). The White Paper on Transportation (ECDGMT, 2011) is the utmost important transportation policy that has described the future vision of the European Commission for transportation (Hubers and Lyons, 2013). The general objectives of these agreements are to.

(i) reduce transportation-related GHG emission by approximately 60% by the year 2050 compared to 1990;

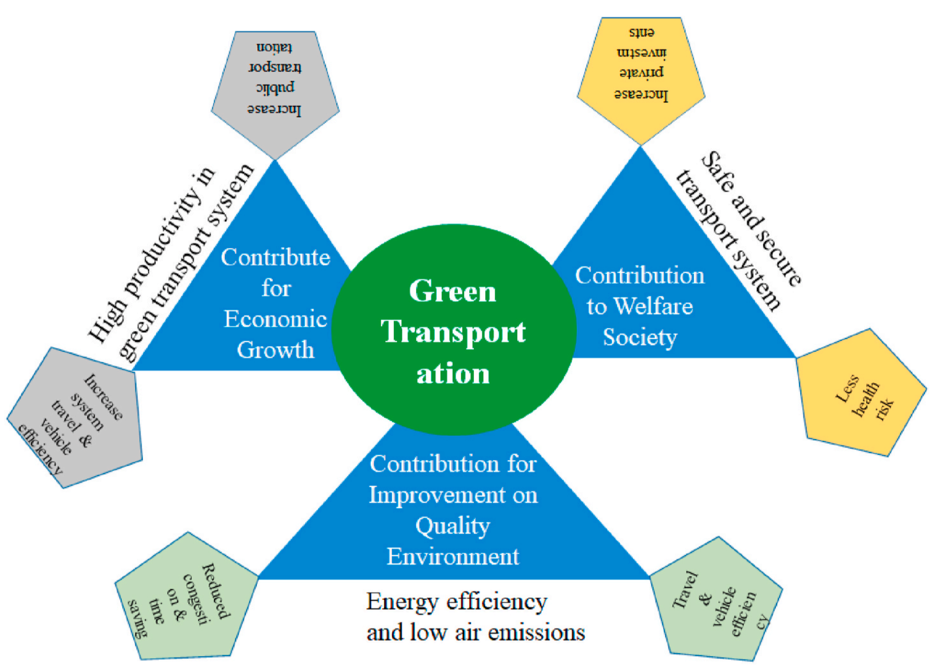

Fig. 2. Key parameters of GT to achieve sustainable mobility in society.

(ii) (ii) reduce oil dependency (import oil) of transportation by approximately 80–95% by 2050;
(iii) (iii) limit the growth of congestion, and
(iv) (iv) facilitate efficient green freight corridors. If the goal is achieved, one-third of road freight (>300 km) can be moved to different modes, for example, rail or waterborne transportations, by 2030 (Psaraftis, 2016).

2. Barriers and challenges

The term barrier and challenges refer to something like a rule, law, or policy that prevents something from happening and something difficult that could be overcome. When considering the barriers and challenges, all stakeholders, namely, transportation operators, warehouse operators, infrastructure operators, cargo owners, environmental organisations, public officials, politicians, industries, R&D organisations, and universities needs to be considered, as the agendas and objectives of all stakeholders are different from each other (Psaraftis, 2016). Barriers and challenges are divided into the regulatory, institutional, technological, financial, and public segments to simplify the agendas of all stakeholders. However, the recent COVID-19 pandemics have opened up a multitude of additional challenges in logistics and supply chains (Klemeš et al., 2020) and also for the continuous worldwide vaccination campaigns (Klemeš et al., 2021b).

2.1. Regulatory barriers and challenges

Over the past few years, population and income growth have changed geographically due to urbanisation and have led to growth in the car-dominated transportation system. This is intensified by the transition to more service-oriented employment, which tends to be located in urban areas, as well as the failure of the national and regional government planning to ensure balanced regional development (Joumard et al., 2017). As a result, there is increasing dislocation between where people live and work. This has failed at the national, regional, and local levels to elucidate that transportation, land-use, housing, and employment policies have been systematically integrated (Deakin, 2019). In the case of the freight industry, low replacement rates and an unwillingness to invest in vehicles with higher emission standards were observed due to intense competition at a time of urbanisation. During the planning, higher taxes could create distortions in the market and damage the competitiveness of domestic transporters. There may be fears of a loss of national competitiveness due to a disruption of the current policies, resulting in lower acceptance of a new technology and service style in the freight industries. The extent of engagement between the public and policymakers is uncertain, so the public acceptance of the global transformation to achieve the GT goals is uncertain (Browne et al., 2012). As a result, this is a serious problem for policymakers, as politicians cannot implement policies without public support.

2.2. Institutional barriers and challenges

Institutional barriers are essential to the development of GT for sustainable mobility. Political issues, policies, taxation, and outdated infrastructure acts are barriers to creating an effective GT system. People with different views about the same values and beliefs make it difficult for government organisations, policymakers, and associated stockholders to establish a common goal or strategy (Rudolph et al., 2015). The case of freight includes conflict among various geographical and jurisdictional boundaries concerning responsibilities to bear the cost of improvements. Investments in one locality can be beneficial to several distant regions, but it is difficult for a single stakeholder to bear the costs of the improvement project due to the absence of coordination. Another significant barrier is implementing new fuels and relevant new technologies (EC, 2016). In the literature, limited data is available about the potentials and performance of alternative fuels and technologies. As a result, customers are not being influenced to purchase sustainable fuel-based vehicles (Steenberghen and Lopez, 2008). Because of such institutional and organisational barriers, the central government is required to establish appropriate institutional structures with a tie-up of local governments in ordered to minimise the disturbance arising from frequent institutional changes.

2.3. Technological barriers and challenges

The application of technological innovations through science, technology, and engineering is acknowledged as a driving force for GT to achieve its sustainable mobility. The use of innovative technologies can control the emissions of environmental pollutants and allow natural resources to be sustainable (Li et al., 2015). However, adaptation, limited access to cleaner technologies, and underperformance of technology are the major limitations and challenges that hamper the effective transition of technology transfer from traditional to innovative (Fan et al., 2018a). Using high-quality fuels and implementing cleaner and highly efficient transportation technology could enhance vehicle efficiency and reduced environmental issues. However, in current government policies, the number of passenger vehicles is increasing. Various technologies (e.g., improved automobile engines, fuels) should be adopted so that pollution load arising from vehicle fleet, usage of poor-quality fuels can be reduced to a significant extent. Instead of using petroleum products, low carbon fuel usage should be optimised. There are various alternative fuels and vehicles currently available in the market or close to commercial feasibility, including liquid biofuels, biogas, battery-operated vehicles, hybrid electric vehicles, and hydrogen fuel cell vehicles (Li et al., 2018). However, there are several confounding factors for weak sustainability, e.g., cost of production, availability of raw materials, development of fuel stations, cost of their maintenance, and poor public perception. Information readily accessible to policymakers and end consumers is very important to implement the new technology.

2.4. Financial barriers and challenges

The financial reason behind poor sustainability is the cost of greening, as green technologies are too costly due to outdated infrastructure in both developed and developing countries. Without the support of a robust infrastructure, it is difficult to take the necessary measures to transition to GT (Pan et al., 2018). For the successful implementation of GT, necessary infrastructures, e.g., road, freight network, etc., are needed, which is the reason why developing countries are lagging (Rodrigue and Notteboom, 2020). These pitfalls call for the renovation of the old infrastructure to meet the present needs of GT. This complete or partial renovation demands a tremendous amount of investment and time for which government and finance agencies are least interested, particularly after the economy in 2008. Transportation policies should be framed to attract investment firms on a large scale (Li et al., 2015).

2.5. Public support

Due to environmental issues, the applicability of green products got more attention, where an Individual's attitude is often considered among essential factors. In most cases, individual vehicle buyers did not prioritise the GHG emission rate, fuel economy, and vehicle registration tax as crucial attributes when purchasing a new vehicle, compared with reliability, automobile safety, fuel costs, and unit price (Kaufmann et al., 2012). The attitude of the public towards public transportation as something that is only to be used by individual sections of the population, viz school children, the elderly people, low- or middle-class people, etc. Some studies have indicated that people perceive public transportation as inferior to private transportation regarding protection, autonomy, and prestige (Browne et al., 2011). In addition to customer choice, public perceptions will also influence policymakers. Policymakers are less interested in low carbon transitions due to fear to get public acceptance and potential public protestation. Therefore, the public should be attracted to involve themselves in formulating policies for a better future (Geels, 2002).

3. Implementation strategies for building GT systems

The traditional approach applied for dealing with increased transportation demands needs additional road space to build a new or vast road infrastructure. This supply-side-oriented attitude has not delivered good benefits due to increased congestion, GHG emission, and the generation of other externalities. A new approach, namely, A-S-I (from Avoid/Reduce, Shift/Maintain and Improve), focusing on the demand side rather than supply side, has been proposed by GIZ (German Service Provider in the Field of International Cooperation) to accomplish a vast GHG outflow decrease, reduced energy utilisation, and less congestion, with the last target to make more decent urban communities (GIZ, 2004). Fig. 3 shows the critical aspects of achieving sustainable mobility by implementing the A-S-I approach of GT. “Avoid” refers to the need to enhance the effectiveness of the transportation system and reduce the travelling demands to the extent possible. This can be achieved by an urban planning concept which is aimed to reduce the distance between the facilities required for daily activities; prioritise first pedestrian circulation followed by cycling, third public transportation (bus, rail, etc.) and as the least option personalise transportation (such as scooter and car). The Shift refers to the improvement of trip efficiency. This can be achieved by promoting public transportation and non-motorised ones (e.g., walking and cycling) (UNESCAP, 2012a). Finally, the improvement strategy refers to focuses on improving fuel and vehicle efficiency as well as optimisation of transport infrastructure. The city authorities have two basic possibilities to influence the behaviour of their citizen, namely, push-and-pull measures, in which pull measures giving incentives, while push measures force penalties. Public transportation, e.g., railways and waterways, is strongly associated with the “pull” approach. Public transportation should be frequent, comfortable, moderate, and dependable to be a reasonable alternative to the passenger’s vehicle (UNESCAP, 2012b). Railways and waterways are generally eco-friendly, compared with different modes of transportation for shifting cargo, and moving towards these modes decreases the ecological damage of cargo transport.

The above A-S-I strategy applies to both developed and developing countries. However, both have a difference in the application in a different context. Table 2 represents the meaning of A-S-I strategies applicable to developed and developing countries. The difference in approaches is mainly due to the level of CO_2. In the case of developed countries, vehicle ownership has reached a high standard, and thus they need to control the absolute concentration of CO_2. On the other hand, the challenge in developing countries is to advance mitigation of CO_2 so that total emission would be lower than usual emission in daily operation (EUEuropa, 2011) (see Table 3).

3.1. Policy background

In relation to GT, policymaking is a rate and extent of corrective actions that can be taken for other environmental hazards arising from transportation to bear the consequences of their activities. From the necessary policies, a successful act on the transportation field was established in 1970 in the form of the National Environmental Policy Act (Caldwell, 1998). Then, the Clean Air Act and Transportation Conformity Act were established to strengthen the transportation system. In the era of the NEPA and Clean Air Act, vehicular emission rules were established in 1990; every single motor vehicle was required to comply with the national standards for exhaust emission. Appropriately, the transportation department issues a “Pollution Under Control” (PUC) certificate to vehicles with a three-month of legitimacy and requires the vehicles to recheck their emission at a frequency of every 3 months to get another PUC. Vehicles that do not meet the acceptance criteria are required to take a corrective measure until a new PUC is received. This has created a lot of public awareness of environmental pollution. Meanwhile, policies that encourage people to walk and cycle would be expected to increase traveller safety and benefit the environment.

3.2. Strategies for public transportation

For the creation of safe urban environments, active travel should be prioritised compared to motorists and sometimes pedestrians and cyclists, as public transportation is a key to controlling the emission level of GHG. While optimising the combination of public transportation, the relative strengths and pitfalls of each mode should be taken into consideration (Table 4)

4. Innovation technology and integration management for green transportation

In times of globalisation and green edge, transportation agencies are under high pressure to adapt to new demands and shrinking revenues. However, the environmental effects of transportation are flexible but are

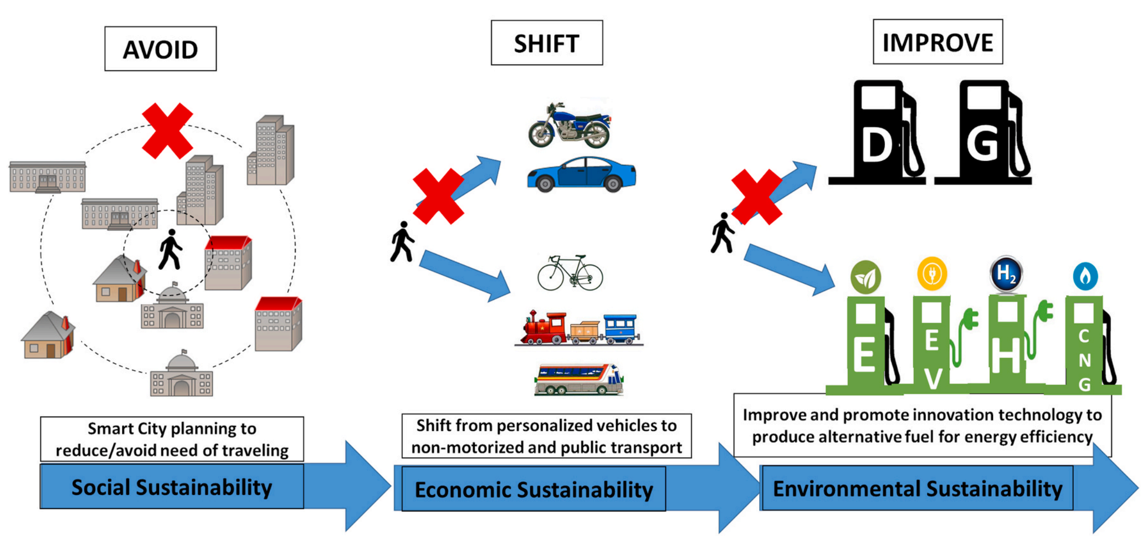

Fig. 3. Avoid-shift-improve (A-S-I) approaches to overcoming the Encountered barriers.

Table 2
Avoid, Shift and Improve strategies with their impact and synergies in developed vs developing countries.

	Avoid	Shift	Improve
Developed Countries (America, Europe, Western Pacific)			
Area of focus[a, h]	To reduce vehicle km by designing compact cities Land usage planning	Shift from private vehicle to non-motorised transportation and public transportation.	Improvement of existing vehicles. Downscale vehicle engine size.
Potential impacts[b,c]	Reduced energy consumption by 10–30%.Life cycle cost reduction	Fulfilment of the need for public facilities within budget or saving money in construction and operation.	Effectiveness change of 40–60% by 2030 attainable at low or negative expenses.
Potential synergies[c,d]	Reduced travel time and improved air quality. Safety and more access that is equitable. More equitable access and increased affordability	Reduced maintenance costs for the road. Reduced urban congestion and equitable access to freight[f]	Enhanced energy security, efficiency, and affordability[f]
Developing Countries (Africa, South-East Asia)			
Area of focus[a, h]	Avoidance of random generation of vehicle km by integrated land usage and transport planning. Develop new urban areas along transit corridors Localised production and a shorter supply chain.	Creation of conditions for the lowest-emitting modes (both freight and passenger). Promotion of shift from private vehicles to non-motorised modes of transport, e.g., bicycle, pedestrian walk and public transportation, e.g., buses.	Ensurement of future vehicles/fuels are eco-friendly, encouraging small, efficient vehicles, e.g., two-wheelers which are very common in Asian countries
Potential impacts[b,c]	Reduced air and water pollution[g] Reduced air emission[g]	Resolution of the problem of public sector budget restraint. On-time project completion by satisfying the need for public facilities.	Change of energy utilisation structure. Mitigation and efficiency potential is in-determinant.
Potential synergies[c,d]	Reduced emission of CO_2 and related gases Reduction in adverse events associated with poor construction and existing transportation facilities.		Diversification of the fuel utilised to climate, air quality, and energy security goals.

Note [a](UNESCAP, 2012c); [b] (Lah, 2015);[c](Lah, 2017);[d](OECD, 2016); [e](Perschon, 2012); [f](UNSG, 2016); [g](Šomplák et al., 2017), [h](Khan et al., 2020).

Table 3
Key performance indicator (KPI) of policy measures in private, public and freight transports.

Pushing away from the motorised private transportation[a]	Pulling new demand for public transport[a]	Green logistics for freight transportation[b]
Promotion of vehicle-free city territories, pedestrian zones, and less polluted economic zones Limit to the number of license plates for cars The imposition of congestion charging/ road valuing and Vehicle registration tax Removal of fuel subsidies and duty fuel Removal of car-oriented subsidies/ sponsorship Promotion of distance-based car insurance schemes Introduction of cycle sharing schemes Develop public transportation[d] The setting of fuel standards[c] Promotion of new vehicle technology and infrastructure Development of intelligent transportation systems	Reservation of road space and higher priority is given to public modes Development of providing better service integrated modes to improve connectivity and convenience The building of beat quality infrastructure with preventive a maintenance program Maintenance of infrastructure and vehicles Provision of information to the public Make it affordable Role of telecommunications and technology Relative costs of ownership and use	• Avoidance of unnecessary wastage of water by implementing beat available recycling technologies[c] • Use of interceptor tanks to avoid contamination while dispensing • Careful management and monitoring for the presence of other hazardous pollutants on site Improvement of the mileage of fuel[c] Enlargement of the average life of tires Reduction of wastage of lubricant released during operation Monitoring of vehicle utilisation regarding both payload and empty running Disposal of used tire casings responsiblyJust-in-time (JIT) strategies[a] Shopping habits[d] Urban sprawl[a]

Note [a](UNESCAP, 2012c); [b](Psaraftis, 2016); [c](Fan et al., 2018a); [d](GIZ, 2012).

highly dependent on transportation technologies for their impact mitigation. In the present scenario, agencies seek new approaches to improve the efficiencies of available resources to offer an enjoyable travelling opportunity to the public. There are some technologies through which GT can be developed (Klemeš et al., 2021a).

4.1. Energy-efficient technology

Energy-efficient technology is rooted in re-design philosophy. Interestingly, over the time course, designers are moving away from improving individual aspects of vehicles towards completely redesigning vehicles from the inception of higher energy efficiency (GIZ, 2012). In the case of the propulsion system, internal combustion engines were widely used at the beginning, where conversion of chemical energy in fossil fuels to mechanical energy was observed mainly through gasoline-powered spark ignition. Time has brought us to move towards battery-driven and fuel-cell driven technologies (Chou et al., 2019). For the case of battery-driven technology, five major attributes such as power, energy, longevity, safety and cost of the battery need to be considered. Li-ion batteries provide more support to the above mentioned five attributes compared to Ni-ion batteries (Axsen et al., 2008). Nowadays, hybrid combustion technology is being utilised to improve energy efficiency. Additionally, 10–15% of the energy from the internal combustion engine of a car is lost due to friction. Lubricants are critical in reducing this drag and enhancing performance. Many research laboratories are developing novel ionic liquids or lubricants that would be able to resolve this friction issue to improve energy efficiency. Near to zero-emission and hybrid technology can be a reliable alternative technology to enhance the performance of a combustion engine. Fuel also plays a vital role to enhance combustion-engine efficiency. Gaseous fuels, for example, hydrogen, natural gas, propane, alcohols such as methanol, ethanol, and butanol, and vegetable and waste-derived oils, are alternative eco-friendly fuels that are used to produce electricity (Kim et al., 2017). Biodiesel is compatible with traditional diesel and can be used in existing diesel engines which can reduce NOx emission. It is the fastest-growing alternative fuel because of its reduced emission

Table 4
Potential barriers and overcome strategies for constructing GT in public transportation.

Category	Type of barriers	Strategy to overcome barriers
PUBLIC BIKING[a]		
Institutional	Lack of knowledge to support the design of a bike-sharing scheme and to control corruption to make it useful in operation.	There should be a department in the city to promote bike-sharing, which should be monitored by GPS tracking to control loss and corruption.
Regulatory	Limited political support leading to a lack of cycling facility and regulation in some cities banning bicycle usage on main roads.	The highest political level must provide Non-motorised transport regulation should allow its marketing considering their health, environmental and economic advantages.
Technological	Lack of technology supporting bike sharing implementation schemes with high efficiency at minimum physical stress.	The direct connection of bikes with the metro station should be strictly linked to bike parking lanes to make it more efficient.
Financial	Reduced financial resources for the initial set-up and bike-sharing scheme.	Following the United Nations Environment Programme (UNEP), City finance should be reserved at least 10% for Non-motorised transportation.
Public	The negative attitude of autonomy and prestige and maintenance and replacement of vehicles demand a lot of investment.	The public need to consider health benefits and fitness rather than pride and prestige.
PARA-TRANSIT[a]		
Institutional	Lack of coordination among various policymakers at a different level of authorisation and responsibility for public transport often delegated to lower-level jurisdictions which are least interested[b]	A dedicated transport authority and policy should be established for local government to ensure an effective and transparent bidding[b]
Regulatory	Limited administrative control to bear responsibility for the effective operation of a route with conflicting schedules and route requirements.	The technically literate administrative agency should be developed so that ownership should be well fragmented and not lie over one person.
Technological	Lack of technically trained generation to invent more ideas about para-transit and the unwillingness of private investors to invest in new lower carbon vehicles	The maximum age of vehicles and the performance level of engines should be fixed to meet emission and fuel economy standards
Financial	Government subsidies are often required for loss-making state-owned operations and lack of insurance coverage[b]	Use climate finance to invest in newer, low-emission vehicles[b]
Public	Public on lower pay scale consider the cheaper vehicle as more affordable irrespective of CO_2 emission	Fuel economy should be taken into consideration instead cost at once.
CONVENTIONAL BUSES[a]		
Institutional	Improper designing of BRT system making private transport as the primary	Establish a dedicated transport authority to design a BRT system for improving routes and public convenience.
Regulatory	Private investors are not interested in new lower carbon vehicles without incentives. Local authority expenditure on energy efficiency is a prime target for cost-saving.	The administrative agency should be trustworthy and expert enough to develop the programme should be developed in such a way as to improve profitability and working conditions.
Technological	Lack of sound technical support to promote the designing of public buses so as to make travel more convenient.	Set standards for an age limit of the vehicle and/or engine performance to meet emission standards and fuel economy.
Financial	Lack of finance for the proper designing of conventional buses. Government subsidies are often required for loss-making state-owned operations and lack of Maintenance cost for bus and infrastructure station.	International sources of funding should be taken into consideration to support proper designing of conventional buses and their maintenance as well.
Public	The limiting its considerable opposition is faced by a private operator and unions growth[c].	Fragmentation of the organisation, integration, and management of public transport. The public should be encouraged for the frequent change to keep public properties well maintained.
BUS RAPID TRANSIT (BRT)[d]		
Institutional	Limitation of institutional/ technical sections to introduce BRT system successfully	International sources of funding should be taken into consideration to support capacity building and institutional development.
Regulatory	The priority of private transports is higher for employees of municipal agencies to get personal benefits.	Awareness about the benefits of schemes that have been successfully implemented in other cities should be raised for the process of design and implementation for those schemes.
Technological	The improper balance between the rate of development of BRT system and the expansion rate of the city.	Cities where BRT schemes have been successfully implemented should be visited by higher authorities for technology transfer and knowledge sharing and to understand implementation methodology.
Financial	A high level of initial investment is required to develop the infrastructure.	The financial budgets of cities that have successfully introduced BRT systems should be looked upon while establishing ours.
Public	The lower quality mode of BRT was usually considered by the public.	Active promotion of competing modes requires making people's involvements. Public awareness shall be raised among the public, emphasising them to consider the advantages of the BRT system rather than pride and prestige.
LIGHT RAIL TRAIN (LRT)[a]		
Institutional	The development and enforcement of LRT: Institutional demand caused by population growth and mass transfer; challenges in developing countries, particularly in cities with the fragmented institutional set-up. Higher standards of operation, maintenance, and administration.	A central authority responsible for the operation, maintenance and administration of LRT shall be established and ensure the existence of a dedicated team with the explicit allocation of responsibility for public transport.
Regulatory	High profile personnel' preference to rail-based	Other travelling modes such as BRT should be considered, and the cost-effectiveness of different solutions to be assessed.
Technological	The incapability of developing countries to implement the latest technology to deliver adequate service.	Internationally implemented good engineering practices should be reviewed and considered technology transfer.
Financial	A high level of initial investment is required to develop the necessary infrastructure as the LRT systems are either built underground or elevated support.	Financial management should be in place to ensure sustainable transport policies receive appropriate funds.
Public	Densification of land usage occurring around the station.	Awareness about the benefits of modern LRVs with the latest

(continued on next page)

Table 4 (*continued*)

Category	Type of barriers	Strategy to overcome barriers
		technology, including passenger information, should be promoted.

Note [a](UNESCAP, 2012c); [b](Pagano et al., 2005); [c](Daniels and Mulley, 2010); [d](Lindau et al., 2014).

capacity without degrading the combustion engine performance (Fan and Klemeš, 2019). In addition to biodiesel, hydrogen fuel cells also can be an excellent alternative fuel candidate (Martins and Brito, 2020).

4.2. Eco-friendly technology

Vehicle performance can be optimised by using several technological developments such as reduced vehicle weight, use of eco-friendly materials and processes for vehicle production, less rolling resistance, and improved transmission (Fan and Klemeš, 2019). A significant reduction in GHG emissions from the production section has been observed utilising green materials without sacrificing safety. In general, fuel consumption can be reduced by reducing the weight of a vehicle. By a rule of thumb, it is proposed that, when accompanied with proper engine design, 5–7% of fuel consumption can be reduced by a 10% reduction in vehicle weight. One ongoing case is given by BMW's new all-electric city vehicle, the i3, which is built from reinforced carbon fibre to reduce its weight by 30–50% as compared to steel. The light body of i3 helps counterbalance the weight of the battery pack used to power the car and guarantees that driving attributes, for example, acceleration, braking, and cornering are better than those of conventional cars (Lambert, 2018).

4.3. Intelligent transportation system (ITS)

In the last decades, the state of the transportation system has changed entirely because of the development of new technologies like computing hardware, positioning system, sensor technologies, telecommunication, data processing, virtual operation, and planning techniques. Significant areas of ITS include freeway management, freight management, information management, emergency handling system, and traveller information system. Many IT applications can play a significant role in risk reduction, mitigation of traffic congestion, and reduction of accident rate, carbon emissions, and air pollution together with increased safety/reliability and traffic flow to offer a satisfactory journey for all modes. Some of them incorporate electronic toll collection, highway data collection, traffic management systems, vehicle data collection, transit signal priority, and so on (Maimaris and Papageorgiou, 2016). Fig. 4 represents the intelligent transport system (ITS), in which data-sharing between government and public transportation is expressed explicitly. Various innovations of ITS can be depicted in electric cars as follows:

- **Satellite-based Air Traffic Control Systems -** Most air traffic systems today are ground-based on satellite-based systems to control the traffic and increase proficiency (Yuniar et al., 2020).
- **Autonomous Cars** - These vehicles use sophisticated cameras and a calibrated road system to navigate the road without the need for a driver. These are safer if the technology is right to ride on complicated roads (Knight, 2017).
- **Smart Roads** - Such roads can sense the number of tyres hitting the ground and inform drivers about traffic patterns, and drivers can decide their route accordingly (Borovilos, 2017).
- **Biometric Vehicle Access** - Using this technology, vehicle owners can unlock and start the vehicle with their fingerprints or eyeball. However, fingerprint readers are more likely to be accepted as compared to retina scanners (Kumar et al., 2014).
- **Comprehensive Vehicle Tracking -** Insurance companies and some state governments are planning to charge fees based on the number of km that a person drives (VTDM, 2020).
- **Active Window Displays or Head-up Display** – The head-up display technology has made the driver a user-friendly ride by providing vibrant images. It is like a navigation system that highlights the next turn, the distance between two vehicles through the windshield (Maimaris and Papageorgiou, 2016).
- **Remote Vehicle Shutdown** - This technology has been implemented in smartphones to prevent thefts. This technology can shut down stolen vehicles. It is expected to apply this remote-vehicle-shut-down technology by 2020 (Mikulec, 2012).
- **Active Health Monitoring –** Ford Motor Company has proposed an idea of steering-wheel sensors or seat-belt sensors that track vital statistics and counts heartbeats through smartphones to help during a heart attack by pulling over-the-call paramedics (Subramaniyam et al., 2018).
- **Peloton Technologies** (Vehicle to Vehicle Communication) – Major problems associated with the Trucking industry are fuel and safety. Peloton, vehicle-to-vehicle communications and radar-based active braking/acceleration systems link heavy trucks to achieve safety and

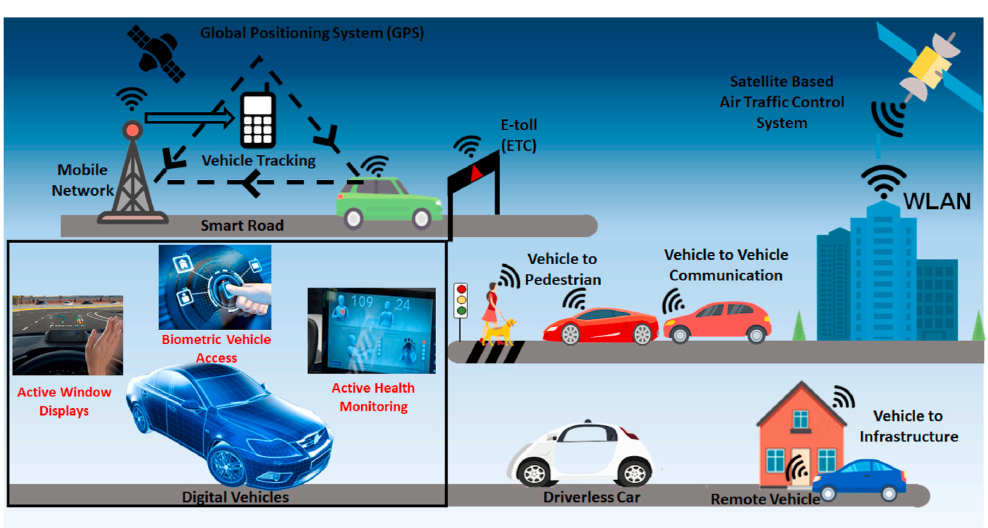

Fig. 4. *Intelligent Transport System (ITS) for Achieving the GT Systems.*

energy saving. It is expected to save fuel by 10% for the second truck and 4.5% for the lead truck (Lammert et al., 2014).

- **Electronic Toll Collection System (ETC)** – The ETC system aims to eliminate the delay at a tollbooth. The ETC system is established to debit the accounts of registered car owners electronically without requiring them to stop. Taiwan was the World's first country to set up electronic tolls on all of its freeways (Abdulla et al., 2018).

4.4. Integrating systems: efficiency by design

"Simplify, and then add lightness" are the expression of the late Colin Chapman, the founder of a sport & racing car manufacturer, Lotus (Wiegand, 2015). While the British car engineer was referring to his rationality of the racing car design, his views resound in numerous advanced design ways to deal with energy efficiency, e.g., substituting steel with lighter materials (Henriksson and Johansen, 2016). During vehicle design, high-strength steel, glass fibre composite, aluminium matrix composite, carbon fibre composite, and magnesium materials can reduce weight by 10–28%, 15–25%, 30–60%, 50–70%, and 30–70%. For internal materials, high-quality foam allows density reduction to 0.4 kg, thermoplastic materials at the back seat, frame, and sculpted light panel reduce weight by 0.3 kg, 0.7 kg, and 0.4 kg, without compromising strength and safety and conventional hybrid and plug-in hybrid cars have their design. However, a standard hybrid has a gas tank to be refilled, and thus, it requires a frequent visit to a gas station. It has a battery pack as well for starting a car or for energy used in the car. The primary source of energy is fuel. In the case of a plug-in hybrid car, the primary source of energy is a battery, and fuel is a supportive source. When comparing both technologies, the plug-in hybrid technology is more user-friendly as it does not require refilling and can be charged at home (EPO, 2017).

4.5. Energy Re-using

In this technology, less fuel usage and more air usage are expected to get via energy reusing. The kinetic-energy recovery technology can be applied to recover and reuse the energy created during the break of a vehicle. In general, the improved energy is stored in a reservoir (i.e., high voltage batteries and flywheels) for later use under acceleration. It has been used in numerous applications, such as racing cars and passenger cars. Ma et al. (EPO, 2017) have built up an energy control system to allow power produced by acceleration and deceleration to be put away as compressed air in a tank. The stored air is then exchanged between the tank and the battery as requirements dictate.

4.6. Solar Impulse Technology

A solar vehicle is an electric vehicle where solar energy is used as a fuel source. It utilises photovoltaic cells to convert solar energy into electricity. The solar-powered flight started in 1974 with Sunrise (Sai et al., 2017). In July 2016, Solar Impulse left a mark on the world by finishing the first-ever round-the-world flight fueled by sun-based energy by the ABB alliance partner. In the year 2020, for the case of solar energy for public transportation, Tube Waysolar Company had developed a solar cargo bike and tube way system (Timeline, 2021). The benefit of Solar Impulse Technology is not only limited to sustainability but also provides control over the ever-rising energy price.

4.7. Integrated management for green transportation

The transportation industry changes the way that it is organised and managed to sustain the environment, economic, and welfare growth. Addressing the issue of urbanisation and transportation is a difficult task, and any effort to achieve sustainability in the transportation system needs to consider all the diverse aspects of the travel demands. The primary aspect includes vehicle growth patterns, emissions rate, traffic management, and efficient land use pattern. All these aspects are interlinked with each other, and it is difficult to solve any of the above aspects in an isolated way. Thus, it is essential to address them at their integration stage (EU25, 2009). The integrated management system for the GT consists of five significant aspects, namely, baseline review, target setting, political commitments, implementation and monitoring, and reporting and evolution, which are graphically illustrated in Fig. 5.

Baseline review is the first and top prioritised step to conduct a joint assessment between associated departments through which the manual baseline has been set up. It reviews data regarding all legal requirements, all internal/external organisations involved, all significant aspects, all political priorities, and existing infrastructure to establish a successful GT system (EU25, 2009b). The next step is to establish a strategic program and an action plan to set a target. It is based on the baseline review and its evolution to find the priorities in establishing a balanced GT from the environmental, social, and economic aspects. During the third step, the established strategic program should be passed for legitimisation to the government, where the role of political commitment comes to action. It requires approval from major political groups, including the mayor, other high-level politicians, different stakeholders, and the general public. With the implementation of the action plan, the objective of sustainability becomes prioritised, and the action plan should be monitored in an appropriate way to feedback to the politicians who determine if the quality of actions is good or not. If not, it allows for taking corrective measures during the process. Finally, the time to evaluate the outcomes through the implementation of GT and the way the management cycle is working. Once the aspects have been set, indicators for each aspect should be identified to achieve the involvement of various departments and all relevant stakeholders, which provide transparency and communication in decision-making. There are some integrated management sectors where GT can be implemented successfully.

4.7.1. Infrastructure management

In the transportation sector, infrastructure maintenance is a crucial challenge for many developing countries, as it requires not only a tremendous amount of money but also necessary technical and organisational skills to keep it in good shape. Particular management policies would incorporate considerable investment in the design of infrastructure for pedestrians and cyclists to reshape the streetscape and public domain, carbon rationing, geologically extended road pricing, traffic demand management, confinements on car parking and access, reduced speed limits, and behavioural change approaches.

4.7.2. Alternative measures in urban transportation

The followings are the alternative fuels, technologies, and management measures to opt for the global public transportation system:

- To promote usage of natural gas vehicles, including liquefied petroleum gas instead of fossil fuels, i.e., hydrocarbons, coal and petroleum
- To develop public awareness towards the usage of electric vehicles
- To award a tax relief to the hybrid electric vehicles
- To promote research on the development of the fuel-cell vehicles
- To generate a safer hydrogen energy way
- To construct a tax relief policy towards the enhancement of biofuel usage
- To build an inspection and maintenance approach for an environmental certification system
- To develop and deploy emission control devices
- To construct bypasses and signals to get better traffic management
- To Promote travelling through metro rail and monorail

4.7.3. Advanced traffic management system

The advanced traffic management system acts as the eyes and ears of the transport information system through Closed Circuit Televisions

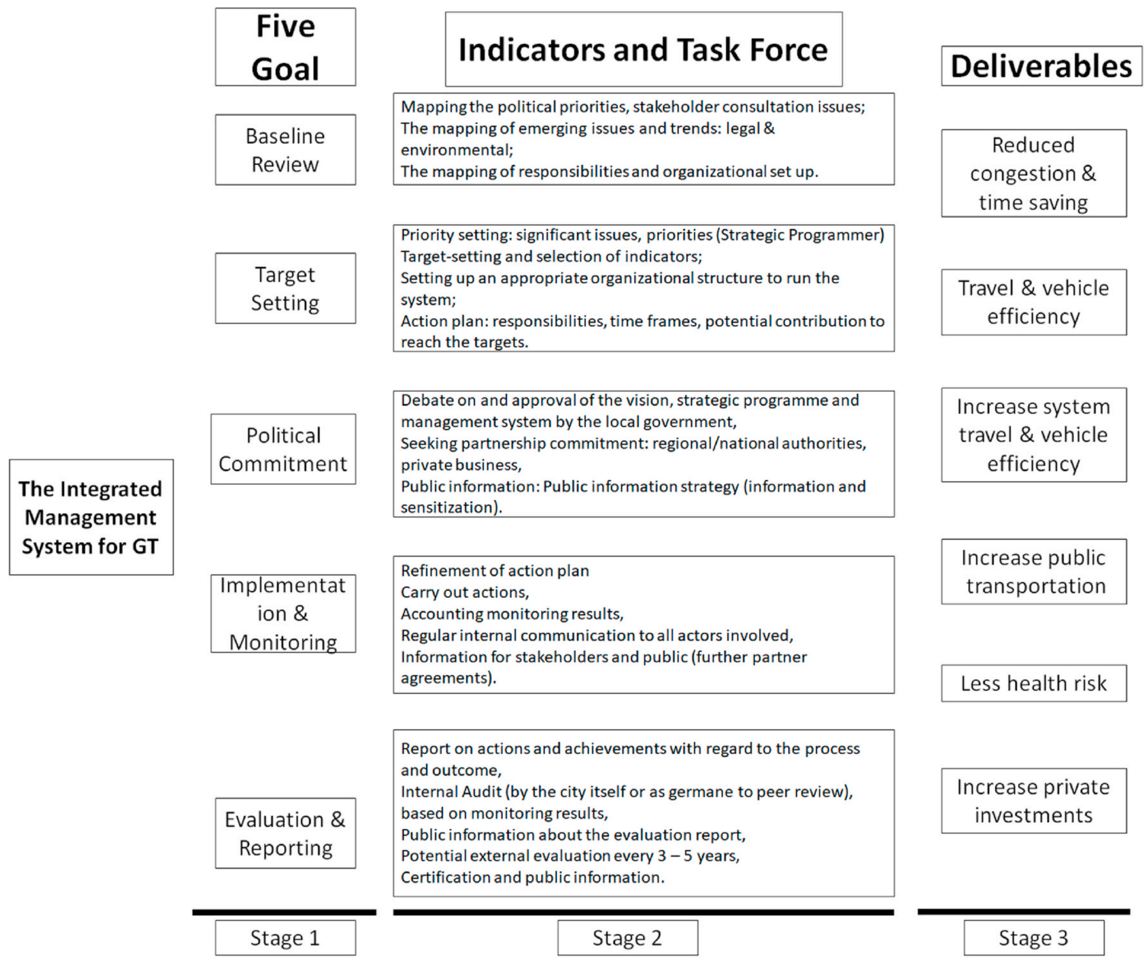

Fig. 5. Stages involved in integrated management System for achieving the green transportation (GT).

(CCTVs) and the automatic accident detection and vehicle location system that collects all traffic information (Gilmore et al., 1993). The data collection units relay the data to a transportation management center for analysis and further processing.

5. The outcome of the A-S-I approach

5.1. Avoid approach: good practice on a municipal carsharing system in Germany

Car-sharing is a transportation way where several persons use one or more collective cars with the "Avoid" approach to the mutual concern of both parties, i.e., person and carsharing provider. The purpose of promoting carsharing is to protect the environment and social security, rather than business and financial benefits (Wang et al., 2019). After adopting this concept, challenges concerning environmental pollution, high-energy costs, limited and expensive parking reduce the number of accidents, and personal satisfaction was solved (Abdulrazzaq et al., 2020). Germany ranks first in the world in carsharing; more than 1.1% of the German population aged older than 17 participate in the carsharing program.

The carsharing concept depends on the following indicators such as location, travel behaviour, and growth of an information system (Munzel et al., 2020). According to location, there are three types of carsharing systems: round-trip, one-way, and free-floating. Among them, in a station-based carsharing system, an average of 42 customers share one car, as do 70 customers in a free-floating system. This growth is because 7700 cars are available at 3900 pick-up stations and 6250 cars are at free-floating stations; the cars are registered by the German municipality (SMT, 2019). While considering the travel behaviour, this concept depends on the attitudes of carsharing members, motivations of carsharing usage, and frequency of usage. Lastly, the concept of information systems in the context of carsharing examines various technologies such as intelligent transportation systems, geographic information systems, and information infrastructures in which Wi-Fi and mobile information systems are available for carsharing members in urban areas. Finally, by avoiding driving private cars and promoting carsharing, an average reduction of 146–312 kg CO_2/y was reported (Jung and Koo, 2018). Similarly, the Netherlands, San Francisco and Calgary have reported 3–18% mobility-related lifecycle greenhouse gas emission by carsharing participation. In all cases, they found that changes in driving behaviour had the greatest impact on overall emission (Amatuni et al., 2020).

5.2. Shift approach: "U-Bike" story in Taiwan

In the early 60s, getting around on a bicycle was reduced to the poorer classes due to the "nouveau riche" concept in people's minds. As a result, the middle class did not keep cycling and used public transportation. The rate of bicycle riders more decreased with economic development initiated, which resulted in the disappearance of bicycles from the city. However, in the past decades, bicycles as a transport mode have returned to the city, with the "go-green" concept to overcome environmental and health issues. In this context, Taipei City Government has launched the "Establishment, Operation and Management of Bike Sharing System" to encourage citizens to use bikes as a shortdistance transit vehicle in 1998 (Yang, 2013). In this mission, the government invested seven years' (started from March 2009) resources in building the most prominent bike rental system in Taiwan (161 stations and 5359 Bike sharing). After successful implementation, the Taiwan government draws the following data analysis to compare people's mindsets. The percentage of males cycling to substitute walking was significantly higher than for females. As far as the age is concerned, the percentage of people at the age of 55–59 having the habit of cycling was significantly higher than those of other age ranges. As far as the education concern, master and above had the habit of cycling was significantly higher than another education background. As far as the earning is concerned, the people who earned 2600–3300 USD were significantly higher than those with different income levels (Lai, 2012). On the other hand, the environmental impact is also significant, and Taiwan has been reported to estimate the average CO_2 reduction as 0.27 $kgCO_2$ per revolution of vehicles use (Chang and Kuo, 2019).

5.3. Improve approach: Taiwan's electronic toll collection (ETC) system

In recent years, passenger cars are the dominant vehicles, followed by buses and trucks on freeways in Taiwan. The first toll station was built in the Taishan District, New Taipei, Taiwan, in 1974 as a manual toll collection system. In February 2005, ETC toll stations with camera gates were launched. In December 2013, the old toll stations were replaced by ETC toll gates with the concept of "the distance-based pay as you go" on all the major freeways (Tseng et al., 2014). After implementing the ETC system, the CO_2 emission was reduced by 12.4%; the costs associated with transaction time fell by 60.1% (Tseng et al., 2014). Some of the advantages of considering the ETC system are efficient use of the transportation system, decreased congestion, emission reduction, revenue generation without corruption, and accident prevention. After reviewing all those benefits, Asia-Pacific Economic Cooperation (APEC) has praised Taiwan's ETC transportation system globally by hailing it as a feasible solution to traffic challenges during the annual meeting of the regional economic forum's Transportation Working Group-2017.

6. Summary and conclusion

Considering the growing interest in addressing sustainability in the global urbanisation process, the current transportation system should be transformed into a future sustainable GT through the implementation of innovative technologies and management strategies. From the context, the conceptual basis of a sustainable transportation system was established in this paper by defining GT and identifying barriers and challenges in establishing the GT. Meanwhile, it was also demonstrated that innovative technologies, a three-step strategy (i.e., A-S-I), and integrated management would play an important and dynamic role in building a GT.

Recently, green supply chains, green tourism, and the green economy are boomingly demanded to achieve global sustainability goals. However, the existing public transportation systems are technically as well as environmentally incapable of moving the world transportation system towards sustainability. However, this paper showed that both environmental and economic benefits could be obtained if the A-S-I strategy would be practised in the present transport system. For example, after implementing the ETC system on the road, Taiwan has reduced 12.4% of CO_2 emission and, at the same time, 60.1% of the infrastructure cost (Tseng et al., 2014). Taiwan has shown a remarkable implementation of shifting approaches among people using the go green concept, through which they have changed people's mindset towards public transportation and enhanced bike sharing among people, without the limitations of education, age and earning. Germany has also shown an outstanding leadership role in carsharing concepts in order to largely support the environment and social security. As a result, they have reduced environmental pollution, energy cost, accident numbers and parking space-related issues. At present, 1.1% of the German population above the age of 17 are participating in carsharing to make Germany rank first in the world. The mentioned cases are just the implementation of a single approach in the existing transportation system. Suppose the public acceptance rate moves on with the rapid advance of technology and proper management panning. In that case, the world will see significantly beneficial environmental and economic outcomes in the future, which will, in turn, support the idea behind the necessity of GT for sustainable development or urbanisation.

In conclusion, it can be said that the implementation of the ASI strategy with innovative technology and integrated management practice is essential in order to convert an existing transportation system into a GT and attaining sustainable development. Although not covered in this review and left to future research, the coordination of GT with green tourism, green supply chain, and green logistics should be done to promote a sustainable circular economy that will replace the current linear economy and be the future economy. With the consideration of the environmental and economic benefits, GT should be regarded as the most efficient system for establishing smart cities and smart tourism.

CRediT authorship contribution statement

Kinjal J. Shah: Conceptualization, Writing – original draft and editing. **Shu-Yuan Pan:** Resources, Writing – review &amp editing. **Ingyu Lee:** Resources. **Hyunook Kim:** Writing – review &amp editing. **Zhaoyang You:** Data curation. **Jian-Ming Zheng:** Writing – review &amp editing. **Pen-Chi Chiang:** Supervision, Writing - editing and proof reading.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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