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Urban sustainable transportation planning strategies for livable City's quality of life

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ABSTRACT

Urban planning and its relevant transportation deploying have a particularly profound influence on the sustainability and livability of a city, and which also be crucial to the quality of life to urban residents at the same time. It was also suggested that the conception of livability should be extended to embrace the concerns associated with the sustainability. However, planning frameworks or assessment patterns that address the dynamics of urban planning and demand for transportation deploying are relatively rare; there also few public policies in related research fields have discussed the effects of the changes in various assessment indicators over time. Furthermore, following the rising advancements in social communication and computer technologies in modern society, the data collection, storage, and processing capabilities of people have improved substantially. And, the emergence of big data or extendible open data facilitates analysis and prediction availability, and enabled people to find immediate solutions to numerous dilemmas encountered. Therefore, based on the aforementioned intention, treating the city as a dynamic process with the trying of introducing the big data or extendible open data for facilitating urban sustainability and livability is undoubtedly worth to explore in further.

The present study intends to initially examine the application of big data in sustainable and livable transportation strategies in Taipei City, Taiwan. Firstly, we investigate previous research on transportation sustainability in various countries to generalize our preliminary list of transportation sustainability indices that satisfy the principles of livable cities. And, key indices were then selected through the Fuzzy Delphi Method by administering a questionnaire to six experts from industrial, governmental, and academic sectors respectively. The research results were applied to develop decision-making strategies for responding to the environmental dynamics of Taipei City's transportation infrastructure system by using the analytic network process combined with a data-mining technique. Thus, big data pertaining to urban transportation were analyzed to predict the future dynamic trends of the key indices and prioritize the sustainable transportation strategies for a livable city under dynamic temporal and spatial changes. Ultimately, the policy implications of this study can not only offer a solution for current needs related to urban planning but also serve as a more transparent decision-making or well selection basis for developing sustainable and livable urban life in near future.

1. Introduction

Although rapid socioeconomic development has accelerated world urbanization and advanced technological progress to shape the today or even tomorrow cities (Newman, Beatley, & Boyer, 2009; Newman & Kenworthy, 2015), it has also placed a sizeable burden and destruction on the urban sustainability and livability. Previously, in order to create an urban ideal environment, Jane Jacobs, a great and extremely famous urban scholar advocated the avant-garde concept of human-scale and the beauty of urban smallness to facilitate the cities more livable and habitable (Gans, 2006; Laurence, 2006). Recently, Professor Geoffrey West who was included in Time Magazine's 2006 list of the 100 most influential people in the world also strongly promoted a grand unified theory which treat the cities as living organisms (Bettencourt, Lobo, Helbing, Kühnert, & West, 2007; West, 2010) for understanding the relationship between human engineered systems as well as the natural environment, and attempt to guide us toward the more sustainable and livable urban life (Bettencourt & West, 2010).

Sustainability and livability are both the most important and ultimate goals that urban life pursues as just mentioned. It was also suggested that the conception of livability should be broadened to embrace the concerns associated with the sustainability (Fidler, Olson, & Bezold, 2011). To the livability and sustainability of cities, urban planning and its relevant transportation deploying have a particularly profound and

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positive effect (Taki, Maatouk, Qurnfulah, & Aljoufie, 2017; Wey, 2015; Wey & Chiu, 2013; Wey, Zhang, & Chang, 2016), and which also be crucial to the quality of life to urban residents at the same time. However, planning frameworks or assessment patterns that address the dynamics of urban planning and demand for transportation deploying are relatively rare. And, most urban planning frameworks or assessments in related fields focus specifically on evaluating environmental impacts and constructing specific analytical frameworks (Deakin, Curwell, & Lombardi, 2002; Shepherd & Ortolano, 1996; Xing, Horner, El-Haram, & Bebbington, 2009) rather than considered the essence of urban development as a dynamic or evolutional process.

Furthermore, following the rising advancements in social communication and computer technologies in modern society, the data collection, storage, and processing capabilities of people have improved substantially. Additionally, the emergence of big data or extendible open data also facilitates analysis validity, and enabled people to find immediate solutions to numerous dilemmas encountered. This background is extremely vital in utilizing the big data or extendible open data to formulate sustainable and livable transportation strategies, which invariably change over time. Considering the time-dependency of decision-making indices (Saaty, 2007) and the immediacy or extensibility of big data (i.e. extendible open data), we thus applied dynamic network process in conjunction with data-mining techniques to treat urban development as a dynamic or evolutional process (Batty, 2017; Batty & Marshall, 2017), and the consequent changes with dynamic or evolutional process invariably cause shifts in demand for urban planning and relevant transportation deploying. In other words, the effects of such shifts over time should be considered and highlighted in order to formulate and reform more appropriate urban transportation development strategies to our cities or even whole metropolitan area.

Based on the aforementioned intention, treating the city as a dynamic process with the trying of introducing the big data or extendible open data for facilitating urban sustainability and livability is *undoubtedly worth* to explore in further. In this study, we primarily intend to initially examine the application of big data in sustainable and livable transportation strategies in Taipei City, Taiwan. This paper proceeds as follows. Firstly, we investigate previous research on transportation sustainability in various countries to generalize our preliminary list of transportation sustainability indices that satisfy the principles of livability. Secondly, to systematically present the opinions of all experts and integrate the consensus of all experts scientifically, the key indices were selected through the Fuzzy Delphi method. Considering the professional fields of the experts and their understanding of the transportation status of Taipei City, two experts from the industrial, governmental, and academic sectors were selected (six in total) to answer the questionnaires. Thirdly, the existing temporal quantitative data of the seven key sustainability and livability indices which constructed by Fuzzy Delphi method were collected. Then, the time-series analysis was performed to establish an autoregressive integrated moving average model (ARIMA) for each index in order to calculate the rate of change in each index from the 2009/Q2 to the 2016/Q4 (31 quarters in total). The rate of change in each index would be applied to reveal the dynamic weight changes in data-oriented dynamic network process to express the dynamic concept of indices or alternatives that change over time. Thus, big data pertaining to urban transportation were analyzed to predict the future dynamic trends of the key indices and prioritize the sustainable and livable strategies for our empirical area under dynamic temporal and spatial changes. On the other hand, the research results were applied to develop decision-making strategies for responding to the environmental dynamics of Taipei City's transportation infrastructure system by using a dynamic network process combined with a data-mining technique. Ultimately, the policy implications of this study can not only offer a solution for current needs related to urban planning but also serve as a more transparent decision-making or well selection basis for developing sustainable and livable urban life in near future.

2. Literature review and research background

2.1. Sustainable and livable cities

Sustainable transportation involves applying the concept of sustainable development to the planning and development of transportation infrastructure. For example, Black (1996) defined sustainable transportation as “satisfying the current transportation and mobility needs without sacrificing the ability of future generations to meet these needs”. The OECD, Institute of Transportation in Taiwan, and Reisi et al. (2014) have indicated that sustainable transportation must be able to respond to the concurrent and long-term environmental, social, and economic needs and impacts. This has been supported by most related studies. In 2009, Taiwan's Institute of Transportation further explained these three dimensions of sustainable transportation. The environmental dimension requires considering the external effects of transportation; the social dimension requires equally satisfying the interests of residents at various socioeconomic levels when improving transportation; the economic dimension requires efficiently using and conserving resources.

Because the abstract nature of the aforementioned principles, specific development strategies and assessment indices must be formulated to further assess the importance and benefits of sustainable transportation. Santos and Ribeiro (2013) indicated that indices should be created to reduce the complexity of sustainable development, maintain scientific objectivity, and improve communication processes. Studies from various disciplines have been conducted to establish indices for sustainable transportation over the years. In 2002, the Institute of Transportation in Taiwan formulated 9 goals and 47 indices encompassing the dimensions of economic efficiency, environmental protection, and social equity according to the index categorization by the UN. Because that study did not cover all topics related to transportation, the dimension of energy use was later included as an additional dimension in 2005. Subsequently, a composite sustainable transportation assessment index system comprising 24 quantitative and 3 qualitative indices encompassing nine goals was formulated.

Acknowledging that the selection of indices has a profound influence on research results, Litman and Burwell (2006) aggregated conventional transportation quality indices and simple sustainability indices according to their convenience and comprehensiveness and constructed a composite sustainable transportation index that covers the economic, social, and environmental dimensions of sustainable transportation. To identify a framework that integrates the information from multiple sources to evaluate transportation sustainability, Awasthi and Chauhan (2011) incorporated the analytic hierarchy process to define nine indices that involved the social, transportation, environmental, energy, and economical dimensions of sustainable transportation; subsequently, numerous data sources (e.g., expert questionnaires, sensors, and models) were applied to evaluate sustainable transportation strategies. To assess sustainable transportation strategies implemented in Taipei City, Shiau (2012) proposed a composite index that incorporated the social, economic, environmental, energy, and financial dimensions of sustainable transportation.

After integrating the transportation indices from previous studies, Santos and Ribeiro (2013) selected 20 indices for the social, economic, and environmental dimensions of sustainable transportation and preliminarily determined their importance on the basis of how frequently they appeared in previous studies. For example, CO_2 emissions, energy consumption, traffic accidents, safety, and accessibility were key indices that had appeared in approximately 70% of the investigated studies. Finally, cases of urban development were used to examine the applicability of sustainable development indices in Rio de Janeiro. To eliminate unnecessary indices, Reisi, Aye, Rajabifard, and Ngo (2014) reviewed previous studies and estimated the existing data of

Melbourne, Australia, to create nine transportation sustainability indices encompassing environmental, social, and economic dimensions; these indices were then integrated into a single composite index.

In addition, regarding the urban livability, Jane Jacobs probably was the most famous proponent and influential activist in the history of American city planning. In *The Death and Life of Great American Cities*, published in 1961, Jacobs advocated the construction of livable cities with abundant street life and commercial and cultural diversity. She stated that only a diverse human-scale community can lead to the foundation of a simple yet great city. Subsequently, many government agencies or research institutions in recent also put forward their own understanding and views. For example, in *Cities in a Globalizing World: Global Report on Human Settlements*, the first global report of the United Nations (UN) Human Settlements Program stated that the provision of public infrastructure, equal opportunities for medical and education services, and safe and comfortable community environments are the prerequisites for building a livable city. The U.S. Metropolitan Planning Commission (MPC) reported that a city must develop safe, reliable, and economically feasible transportation options to lower the costs of household transportation, reduce national reliance on imported raw petroleum, and improve air quality. In Singapore, the Urban Land Institute and Center for Liveable Cities also maintained that environmentally friendly transportation systems must be established to eliminate traffic pollution and congestion, which undermine the quality of a city's livability.

Moreover, Evans (2002) addressed livelihood and ecological sustainability as two aspects of city livability. Livelihood indicates satisfactory living conditions. When the lifestyles of city residents cause environmental decline, the quality of life of residents is diminished. A livable city satisfies the livelihood needs of all its residents under the prerequisites of ecological environmental protection. Fidler et al. (2011) also emphasized that many urban illness or social threats, including urban sprawl, rising energy costs, climate change, and fiscal challenges are likely to work against efforts to make communities more livable. On the basis of these findings, we should develop strategies that counter these negative illness or threats while also improving our urban life. In the most recent period, Zhan et al. (2018) conducted a large-scale questionnaire survey on 40 major cities in China in order to fill the gaps of past studies for urban livability. The results show that the six dimensions of urban livability (including public facilities, natural environment, socio-cultural environment, urban security, environmental health, and convenient transportation) have significant and positive impacts upon overall satisfaction with urban livability, of which the natural environment, convenient transportation, environmental health are the greatest contributing factors.

In summary, most studies have maintained that a livable city must encompass numerous aspects such as economic development, social security, environmental conservation, history and culture, and transportation. And, transportation planning is crucial for constructing public infrastructure; the diversity, safety, convenience, and sustainability of transportation activities are vital for a strong, fair, and efficient living environment as well as the livability of a city. On the other hand, sustainable transportation is any transportation mode that satisfies current transportation needs without sacrificing the needs of future generations, the evaluation of which involves environmental, social, and economic dimensions. The environmental dimension emphasizes ecological conservation and alternative energy development; the social dimension emphasizes equality and safety; the economic dimension emphasizes the balance between cost and efficiency and the improvement of economic competitiveness.

2.2. Big data and its applications

The popularity and tide of big data have resulted in the development and applications of technologies and methods aimed at effectively using massive amounts of data to support decision-making and knowledge discovery activities (Storey & Song, 2017). For example, in the context of smart sustainable cities, big data analytics denotes a collection of sophisticated and dedicated software applications and database systems run by machines with very high processing power, which can turn a large amount of urban data into useful knowledge for well-informed decision-making and enhanced insights pertaining to various urban domains, such as transport, mobility, traffic, environment, energy, land use, planning, and design (Bibri & Krogstie, 2017). Despite attention and embrace from many scientific researchers or fields, the definition of big data is still highly controversial and remains ambiguous. One of the major widely debate is that the meaning of big data is not accurate enough. Due to big data which may means data itself are too big or large that could not be processed easily in the past, but which maybe could calculate smoothly through the amateur software and hardware now (Manovich, 2011). Thus, big data itself is, in many ways, a poor term with no precisely defined (Boyd & Crawford, 2012; Manovich, 2011). On the other hand, the meaning or definition of big data suggests that data are too big or large only in relation to our current computational power rather than exact defining characteristic of this new data ecosystem (Floridi, 2012). In fact, some of the big data that we praise highly now (e.g., Twitter messages about a particular topic) are not even larger than the census data (e.g., government open data about the socio-economic survey) that were not recognized as big data in the early days (Boyd & Crawford, 2012). As described by Professor Michael Batty, a renowned British urban planner and scientist of complex urban systems, big data are data bodies that expand continually and thus continue to challenge the capacities of data analysis tools (Batty, 2013).

According to the discussion aforementioned, we thus find another major widely debate is that big data should not only refer to very large data sets, but also to the tools and procedures used to manipulate and analyze them (Boyd & Crawford, 2012). In other words, the most important value of big data does not rely on the amount or quantities of data itself. As described by Professor Geoffrey West, a renowned British theoretical physicist and scientist of grand unified theory of sustainability (West, 2010), science is meritocratic and not all data are equal (West, 2017). In some extreme situations, we even must try to eliminate large part of data sets that is useless and may confuse experimental results (e.g., the discovery of the Higgs boson and top quark). Thus, maybe for most scientific fields, we have to put our main effort and focus on exploring or mining critical parts that hidden in data sets via design techniques, analytical tools, execution procedures, decision support systems, or even creative solution algorithms (Chang, Wey, & Tseng, 2009; Janssen & Kuk, 2016; Lai & Huang, 2017; Wey & Wu, 2007) rather than the dominate characteristic of 5Vs (volume, velocity, variety, veracity, and value) or precise definition of the big data. Then, it thus would inform or even enhanced decision making as well as future strategies we needed, especially in the situation of new urban data streams generating rapidly (Batty, 2012).

Another major widely debate about big data or large dataset is that may lead to decision paralysis, or at least decision delay, that is, the allure of data encourages decision makers to wait more possible information (Håkonsson & Carroll, 2016). And, the delayed decisions may ultimately not be applicable to rapidly changing urban systems (Batty, 2012). Although it seems that big data makes it possible for us to collect more data to find more useful information, the truth is that more data do not necessarily mean more useful information. It may contain more ambiguous or abnormal data (Tsai, Lai, Chao, & Vasilakos, 2015; West, 2017). Therefore, bigger data (more data) that we wait for or search for are not always better data (Boyd & Crawford, 2012). Moreover, the above decision scenarios also specifically alert that there is a tendency pursuing more data that just due to decision makers could (easily) obtain, not because the data would facilitate or enable decision makers to make the right or better decisions (Håkonsson & Carroll, 2016).

As discussed above, although there are still many questions and controversies that still need to be resolved, the cooperation between big

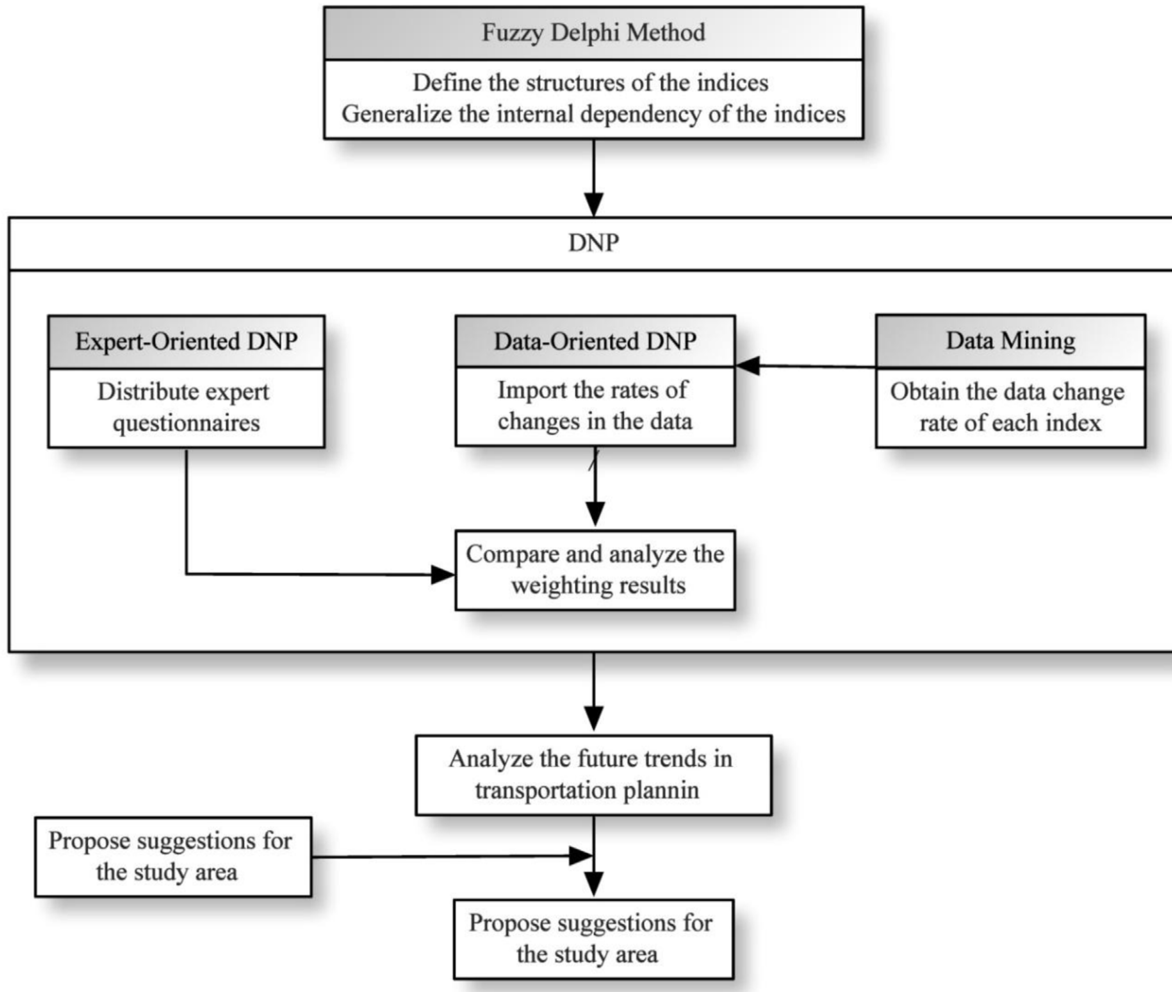


Fig. 1. The goal and research design of this study.

data and urban development is still booming and continues to advance. Numerous types of datasets are applied to research on urban and transportation planning. Considering the importance of dynamic information in understanding urban spaces, Soto and Frias-Martinez (2011) used mobile phone data from urban spaces and defined five clusters of land use. Examples of big data being applied to research on travel routes include time-series global positioning system data being used to analyze the travel routes of taxicabs (Zheng, Liu, Yuan, & Xie, 2011), smart card systems—the usage of which has increased as a fee-payment mechanism in urban public transportation—have been employed in several studies to investigate the temporospatial dynamics of urban public transportation trips (Bagchi & White, 2005; Pelletier, Trépanier, & Morency, 2011). Social media data, although having emerged only recently, have expanded rapidly and now provide a massive source of big data for real-time information on travel patterns, such as transportation information from the keywords in social media (Gal-Tzur et al., 2014).

Recently, it is worth to note that various scientific innovations in urban development field are flourishing especially between cutting-edge technologies and its emerging requirements (Alazawi, Alani, Abdljabar, Altowaijri, & Mehmood, 2014; Mehmood & Graham, 2015; Suma, Mehmood, Albugami, Katib, & Albeshri, 2017). Often of these cutting-edge technologies and its emerging requirements claim that they could promote the sustainability and livability of the city or even make the city, society or environment smarter. For example, Ahmad and Mehmood (2016) suggested that future cities are driven by the developments in Information and Communication Technology in further, and logistics will play a critical role in future cities due to the increasingly micro-dynamic nature of socio-economic and globalised production and consumption patterns. Schlingensiepen, Mehmood, and Nemtanu (2015) and Schlingensiepen, Nemtanu, Mehmood, and McCluskey (2016) also emphasized the application and benefits of cutting-edge technology. Coincidentally, they both believed that future cities will be driven through advanced complex ICT systems (i.e., autonomic transport management system) that harness the power of data collected from distributed network of sensors in order to provide personalized information and services to its consumers under sustainability and other constraints. In similar way, Naim and Rashid (2015) declared enterprise systems and supply chain management systems as a critical part of smart city setting could facilitate sustainability and have a positive impact on corporate financial returns. Therefore, enterprises should pay more attention to the three dimensions (i.e., economy, society and environment) of sustainability.

Due to the industry-driven, top-down, design approaches completely ignore the self-organization, the self-sustaining structures, and the complexity of urban systems (Batty, 2008; Batty & Marshall, 2017; Bettencourt et al., 2007), Naim and Rashid (2015) also deeply reflected that the ICT-based and industry-driven approaches maybe are not the only solution for urbanization and future city designs. Based on the above insightful rethinking and reflecting, we thus realize that the common ground and means of ICT-based or industry-driven approaches often tend to directly achieved sustainability or livability through innovative technologies, mechanisms or intelligent systems. When enjoying great technological convenience and business benefits aforementioned, however, we have to notice that the implementation of these innovative technologies, mechanisms or even intelligent systems requires a lot of data resources, hardware architecture, construction cost as well as probably facing more unknown risks or complexities. Comparing to traditional planning, these innovative technologies, mechanisms or intelligent systems may be necessary to assessment carefully via relevant experts or research institutions in further.

3. Research design

The goal of this study was to establish transportation sustainability indices for a livable city, to predict their future dynamics, and to formulate sustainable urban transportation strategies that fulfill the time-dependency of the indices. The research design (Fig. 1) is described in the following four steps:

Step 1 Collect and review literature on livable cities and sustainable transportation worldwide. Examine and analyze the literature to generalize a list of transportation sustainability assessment indices for a livable city.

Step 2 Select the applicable indices for the proposed research model and the conditions of the area of empirical study through the Fuzzy Delphi Method (FDM). Generalize the dependency relations among the indices for the subsequent modeling process.

Step 3 Use data mining to analyze the transportation data to predict dynamic changes in the indices over time. Operationalize these changes in the DNP by examining the priorities of the urban transportation sustainability indices to develop a questionnaire survey for a panel of experts. Analyze the results of the data-oriented and expert-oriented DNPs and compare the findings. For further application of the rates of changes in the index data and to identify current index weights and predict future weight changes, this study investigated the raw data through a time-series analysis, a data-mining tool that is frequently used to predict continuous variable processes. This was employed to establish a prediction model for each index. The DNP proposed by Saaty (2007) can be applied in sturctural or functional form. The structural form incorporates different time points as alternative programs and compares the criteria with the programs in pairs. The functional DNP involves using the standard dynamic judgment matrix A(t), which explicitly includes the functions of time. The typical form of a judgment matrix in dynamic form is:

$$\mathrm{A(t)} = \begin{bmatrix} a_{11}(t) \\ a_{21}(\mathrm{t}) \\ \vdots \\ a_{n1}(\mathrm{t}) \end{bmatrix} \begin{matrix} \\ \cdots\cdots \\ \cdots\cdots \\ \\ \end{matrix} \begin{matrix} a_{1n}(t) \ 0, \ =. \\ a_{2n}(t) \ 0, \ =. \\ \vdots \ 0, \ =. \\ a_{nn}(t) \ 0, \ =. \end{matrix}$$

As in the discrete case, when *A(t)* is consistent, we have $a_{ij}(t) = w_i(t)/w_j(t)$. The functional DNP, which explicitly incorporates time variables, clarifies the dynamic weight curve of each factor according to the relative rate of change in each factor over time, the findings of which are then assessed by experts.

Step 4 Generalize and discuss the processes and results of the empirical analysis and propose suggestions on formulating sustainable transportation strategies for the livable city examined in this study.

4. Empirical study and analysis

4.1. Area and range of the empirical study

An area that fulfills the goal and model of this study was selected for the empirical study. Considering the environmental, social, and economic dimensions under investigation, Taipei City (Fig. 2) was selected as the area of the empirical study for the following reasons:

(a) Taipei City is the political, economic, and cultural center of Taiwan. The total population of Taipei City in October 2014 was 2,697,644. Data from that year show that residents owned 286 cars and 385 motorcycles per 1000 population in 2013. Thus, the number of private vehicle trips in Taipei City is high. Moreover, the population concentration is also high, and residents experience difficulty commuting between New Taipei City and Taipei City. These transportation needs require immediate attention.

(b) Urban development strategies for Taipei City must promote harmony between humans and nature, a balance between the cityscape and nature, and macroeconomic objectives, social harmony, and ecologically virtuous cycle. Therefore, the Taipei City Government's vision for future development is focused on foresight, pleasure, livability, culture, ecology, information, and safety. *White Paper on Transportation Policies* from the *2020 Program for the Long-Term Development in Taipei* lists sustainable transportation, affinity and humanism, and livability and safety as the visions of development of the city government for formulating the development goals and executing the policy strategies.

(c) On the actual transportation construction, major development plans for the city's public transportation network have neared completion. In 2013 and 2014, the Xinzhuang, Xinyi, and Songshan lines of Taipei's mass rapid transit (MRT) network were opened, increasing the total length of the MRT to 129.2 km. In 2014, daily peak traffic was reached 1.63 million trips. The Taipei City Government has promoted a dynamic bus information system to improve the quality of bus services by fitting buses with GPS tracking systems and communication devices to provide real-time information on bus travel times for seamless information services.

The Taipei City Government has also promoted the *Taipei Bike Sharing System Establishment and Management Program* to encourage people to use bicycles for short trips. A network of urban bicycle lanes has also been integrated into the bike sharing system to encourage people to use low-pollution, low-energy public bicycles instead of private motor vehicles for short trips, thereby mitigating traffic congestion, environmental pollution, and energy exhaustion.

In summary, the current transportation policies implemented by the Taipei City Government are oriented toward sustainable transportation, and the orientation of the urban development also satisfies the visions of a livable city. Thus, Taipei City is within the scope of this study. Additionally, the city's transportation demand is high, and its fully developed transportation infrastructure provides a massive source of transportation data for follow-up research procedures. Therefore, Taipei City was selected as the area of the empirical study to investigate the key indices and strategies satisfying Taipei City's livability and transportation sustainability.

4.2. Establishing the target system and preliminarily selecting the indices

The following figure shows the sustainability indices drawn from the discussed studies and applied to the livable city concept (Fig. 3) for the follow-up FDM and empirical analysis. The preliminarily selected indices were based on the environmental, economic, and social dimensions. The leading indices were CO2 (greenhouse gas) emissions per unit, nonrenewable energy and fuel consumption, and air and noise pollution for the environmental dimension; infrastructure, congestion severity, and household expenses on transportation for the environmental dimension; and accessibility to public transportation and safety for social dimension. Other indices representative of transportation sustainability were the density of land use, transportation diversity, land consumption in transportation, and the use of public and non-motor vehicles. Table 1 lists a description of the indices.

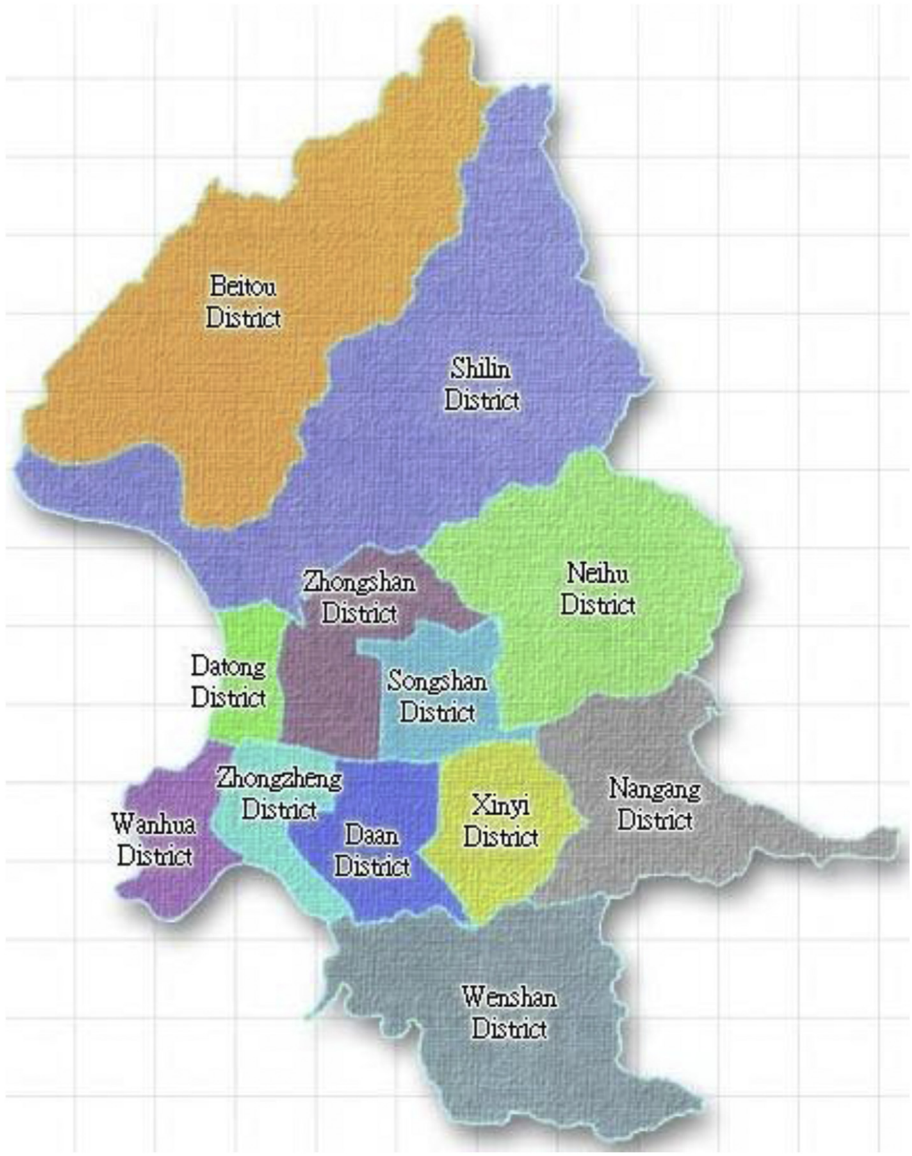


Fig. 2. Administrative districts of Taipei City.

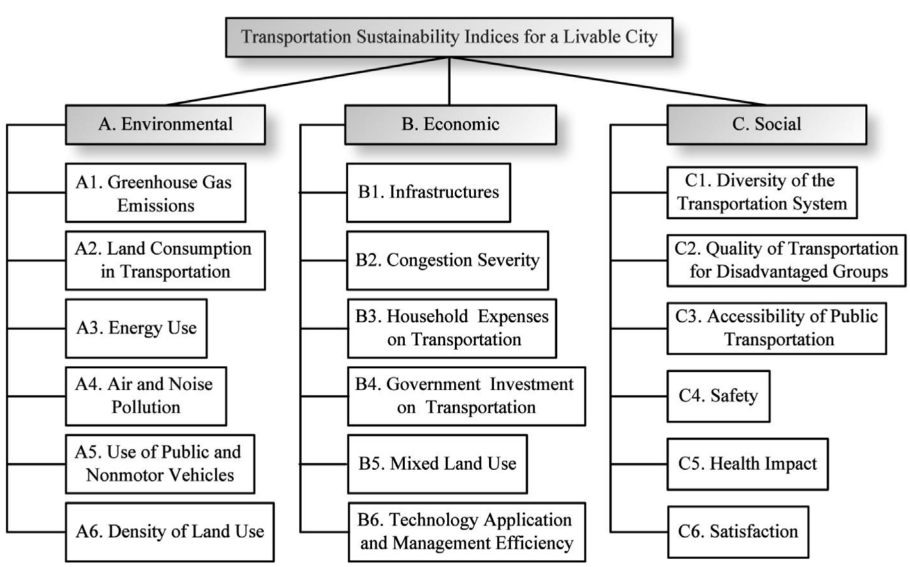


Fig. 3. Research framework of a livable city concept.

Table 1
Descriptions of the transportation sustainability indices for a livable city.

Dimension	Index	Description
A.Environment	A1. Greenhouse Gas Emissions	Effective control and monitoring of greenhouse gas emission in urban transportation to reduce damage to the ecological environment and human health, thereby achieving the sustainable development of urban living and the natural environment.
	A2. Land Consumption in Transportation	Effectively plan and manage land use in transportation to improve land resource use efficiency and mitigate the environmental impact of transportation, thereby safeguarding the quality of daily living and the natural environment.
	A3. Energy Use	Develop renewable energy to reduce people's reliance on nonrenewable energies (e.g., fossil fuels) to enabling effective energy recycling, mitigate the impact of nonrenewable energy use on the environment and human health, and attain the goals of livability and sustainability.
	A4. Air and Noise Pollution	Effectively control and monitor noise and emissions from urban traffic to mitigate damage to the ecological environment and human health, thereby achieving sustainability in both the urban environment and the natural environment.
	A5. Public and Non-motor Vehicle Use	Promote the use of public and non-motor transportation vehicles and reduce the use of motor vehicles to mitigate the impact of vehicles on the natural environment and attain the sustainable development of urban daily living and the natural environment.
	A6. Density of Land Use	Promote high-density land use to reduce travel distances and times to lower unnecessary resource use and transportation trips and thereby improve the urban environment.
B.Economy	B1. Infrastructures	Promote the transportation quality, convenience, and livability of the city through constructing a comprehensive range of transportation infrastructure services to achieve the objectives of economic efficiency and sustainability in urban transportation.
	B2. Congestion Severity	Provide diverse transportation vehicles, encourage minimal use of private vehicles, and strengthen the overall transportation system network to reduce traffic congestion and improve the livability of the city, and thereby achieve the objectives of economic efficiency and sustainability in urban transportation.
	B3. Household Expenses on Transportation	Develop diverse, safe, reliable, and economically feasible transportation options to reduce household expenses on transportation and promote the quality of daily living, thereby improving the livability and transportation efficiency of the city.
	B4. Government Investment on Transportation	Improve the efficiency of the government's investment in transportation infrastructure and policy, lower the cost per unit of the investment, and prioritize investment in environmentally friendly transportation systems and infrastructure to improve the efficiency of resource use.
	B5. Mixed and Use	Promote mixed land use to shorten travel distances and reduce the demand for commuting to reduce household expenses on transportation and improve transportation efficiency.
	B6. Technology Application and Management	Upgrade technology, improve the energy use and capacity of transportation units, and enhance the efficiency of transportation system operations, monitoring, information management, and law enforcement through innovative governance (e.g., promote the use of hybrid vehicles and smart transportation systems).
C.Society	C1. Diversity of the Transportation System	Provide various types of transportation vehicles to satisfy the transportation needs of different groups to achieve social sustainability and enhance the livability of the city.
	C2. Quality of the Transportation for Disadvantaged Groups	Consider and satisfy the basic transportation needs of disadvantaged groups (e.g., persons with disabilities, children, elderly citizens, low-income earners, and the residents in remote areas) in designing transportation systems to promote the livability of the city for all people and maintain the equality in urban development.
	C3. Accessibility of the Public Transportation	Improve the public transportation network and its accessibility and convenience to reduce the use of private vehicles, lower traffic congestion, and satisfy the basic transportation needs of all people, thereby attaining the livability of the city and the equality in its development.
	C4. Safety	Enhance road and sidewalk safety to minimize the risks of traffic accidents and casualties to mitigate the consequent social damage, thereby achieving social sustainability and enhancing the livability of the city.
	C5. Health Impact	Reduce traffic pollution and accidents to mitigate their damage to public health, thereby improving the livability of the urban environment and sustainable transportation development.
	C6. Satisfaction	Improve the of transportation infrastructure (e.g., roads and public and non-motor transportation vehicles) to raise public satisfaction, thereby enhancing the livability and sustainability of the urban environment.

4.3. Using the FDM to select the transportation sustainability indices that fulfill the goals of developing Taipei City as a livable city

To establish the transportation indices and strategies and objectively fulfill the demands of the area of the empirical study and the considerations of planners to identify the most appropriate and efficient indices and strategies, the transportation sustainability indices (Table 1.) were examined through an FDM expert questionnaire to affirm the objectivity of the indices for further strategic planning. Considering the professional fields of the experts and their understanding of the transportation status of Taipei City, two experts from the industrial, governmental, and academic sectors were selected (six in total) to answer the questionnaires.

Table 2 depicts the questionnaire results. The expert consensus value G_i is > 6 for most of the indices. In other words, all 18 indices were considerably representative of transportation sustainability in Taipei City. However, for the operability of future studies, these indices were selected from the steepest region of the consensus curve as the threshold value. The three regions with the largest differences in G_i values on the curve are listed as follows: (a) accessibility of public transportation (Index C3) versus use of public and non-motor vehicles (Index A5), with a difference of 0.34; (b) health impact (Index C5) versus diversity of transportation systems (Index C1), with a difference of 0.19; (c) mixed land use (Index B5) versus technology application and management (Index B6), with a difference of 0.71. To obtain a suitable number of selected indices for the follow-up research procedures (total number of indices selected = 7), Index C5 (health impact) was selected as the threshold in this study (threshold Value = 7.30).

4.4. Predicting the dynamic trends of the transportation sustainability indices through data mining

Temporal quantitative data of the seven selected transportation sustainability indices were collected. A time-series analysis was performed to establish an autoregressive integrated moving average model (ARIMA) for each index in order to calculate the rate of change in each index from the 2009/Q2 to the 2016/Q4 (31 quarters in total). Because of the limitations in acquiring the index data, only the actual available data could be used as the index application data.

For the operation and prediction consistency, the unit of

Table 2
Index assessment results in the FDM expert questionnaire.

Index	Conservative Value (Ci)		Optimistic Value (Oi)		Singular Value (a)		Geometric Means			Certified Value (Zi)	Expert Consensus Value (Gi)
	min	max	min	max	min	max	Ci	Oi	Singular Value		
A1. Greenhouse Gas Emissions	4	7	6	9	5	8	5.67	8.30	6.90	1.63	6.99
A2. Land Consumption in Transportation	6	8	8	10	7	9	7.13	9.47	8.14	2.33	8.30
A3. Energy Use	5	6	8	9	7	7	5.79	8.19	7.00	4.41	6.99
A4. Air and Noise Pollution	4	8	6	10	5	9	5.71	8.19	6.53	0.49	6.95
A5. Use of Public and Non-motor Vehicles	4	9	8	10	6	9	6.24	8.94	7.64	1.71	7.59
A6. Density of Land Use	4	8	6	10	5	9	5.68	8.21	6.88	0.53	6.95
B1. Infrastructure	4	7	6	10	5	8	5.67	8.28	6.90	1.60	6.98
B2. Congestion Severity	4	8	8	10	6	9	5.96	8.79	7.39	2.83	7.37
B3. Household Expenses on Transportation	4	8	6	10	5	9	5.60	8.07	6.99	0.47	6.83
B4. Government Investment on Transportation	4	8	8	10	6	9	6.19	8.81	7.44	2.61	7.50
B5. Mixed Land Use	4	6	6	9	5	7	5.28	7.93	6.29	2.65	6.60
B6. Technology Application and Management	4	7	6	9	5	7	4.68	7.11	5.75	1.43	5.89
C1. Diversity of Transportation Systems	4	8	6	10	5	8	5.99	8.23	6.90	0.24	7.11
C2. Quality of Transportation for Disadvantaged Groups	4	8	6	10	5	9	5.92	8.23	7.31	0.31	7.08
C3. Accessibility of Public Transportation	4	10	8	10	6	10	6.74	9.12	8.07	0.38	7.93
C4. Safety	5	8	9	10	7	9	6.74	9.65	8.30	3.91	8.20
C5. Health Impact	4	8	7	10	6	9	6.17	8.43	7.42	1.26	7.30
C6. Satisfaction	4	8	6	10	5	9	5.79	8.38	7.03	0.59	7.08

Note: Grey-highlighted areas indicate the indices that fulfilled the threshold.

Table 3
Descriptions of the actual application data of the indices.

Index	Measurement Data	Relationship with the Index	Data Source
A1.Land Consumption in Transportation	Ratio of the amount of land used for transportation to the total amount of land for public infrastructures	Reveals the extent of the importance that the city government associates with transportation construction and the traffic status possibly seen in the city.	- Taipei Statistical Database - Department of Urban Development, Taipei City Government
A2.Use of Public and Non-motor Vehicles	Rate of public and non-motor transportation vehicle use	The promotion and use of public and non-motor transportation vehicles are key criteria for the livability of a city.	- Statistics Inquiry, Ministry of Transportation and Communications - Taiwan Railways Administration, Ministry of Transportation and Communications - Taipei Rapid Transit Corporation - Taipei Statistical Database - Taipei Transportation Statistical System
B1.Congestion Severity	Number of cars/motorcycles per 1000 population	The total number of cars and motorcycles reflects the severity of traffic congestion at a certain extent.	- Taipei Statistical Database - Taipei Transportation Statistical System
B2.Government Investment on Transportation	Budgets of the Taipei Department of Transportation	The efficiency of government investment on transportation construction directly influences the quality of urban transportation.	- Taipei Statistical Database - Department of Urban Development, Taipei City Government
C1.Accessibility of the Public Transportation	Numbers of MRT stations, joint bus routes, and YouBike stations	The number of public transportation stations directly affects the intentions of people to use public transportation.	- Taipei Transportation Statistical System
C2.Safety	Average monthly number of traffic accidents	Reducing the number of traffic accidents promotes urban transportation safety to at a certain extent.	- Taipei Transportation Statistical System - Traffic Division, Taipei City Police Department
C3.Health Impact	Standard index average monthly pollution levels	Air quality is crucial to the health and quality of life of people. Transportation waste emissions are a major cause of urban air pollution.	- Environmental Quality Data Storage System, Environmental Protection Administration

observation was set as one month; data observations from January 2009 to December 2014 (60 data observations in total) were prioritized. Table 3 illustrates the data on the actual application of the indices, how the data are related to the indices, and the data source.

The ARIMA combines two types of data-generating process models, namely the autoregressive (AR) model and the moving average (MA) model. Formula (4.1) shows the generalized $AR_{(p)}$ model; Formula (4.2) depicts the generalized $MA_{(q)}$ model; and Formula (4.3) displays the formal definition of $ARIMA_{(p,q)}$ (Yang, 2010).

$$y_t = a_0 + \sum_{i=1}^{p} a_i y_{t-i} + \varepsilon_t \tag{4.1}$$

In Formula (4.1), a_0 represents the intercept of the constant; p represents the lag; a_i is the coefficient of y_{t-i}; ε_t represents white noise.

$$y_t = a_0 + \sum_{i=1}^{q} b_i \varepsilon_{t-i} \tag{4.2}$$

In Formula (4.2), a_0 represents the intercept of the constant; p represents the lag; b_i is the coefficient of ε_{t-i}; ε_t represents white noise.

$$y_t = a_0 + \sum_{i=1}^{p} a_i y_{t-i} + \varepsilon_t + \sum_{i=1}^{q} b_i \varepsilon_{t-i} \tag{4.3}$$

Each index can be used to generate multiple models with a good fit. The model with the closest fit for each index was determined according to the Akaike information criterion (AIC) and the Schwarz Bayesian criterion (SBC). The smaller the AIC and SBC were, the higher the

Table 4
Best-fit model and formula derivation of each index.

Index	Index Application Data	Finalized $ARIMA_{(p,d,q)}$
A1	Ratio of the amount of land used for transportation to the amount of land used for all public infrastructure	$ARIMA_{(1,1,1)}$
A2	Use of public and non-motor vehicles	$ARIMA_{(4,1,5)}$
B1	The number of cars and motorcycles per 1000 population	$ARIMA_{(0,1,2)}$
B2	Budgets by the Taipei Department of Transportation	$ARIMA_{(0,1,1)}$
C1	The number of MRT stations, bus routes, and YouBike stations	$ARIMA_{(1,1,1)}$
C2	Rate of vehicle accidents (cases/10,000 vehicles)	$ARIMA_{(3,1,(1,3))}$
C3	Pollutant standards index	$ARIMA_{(3,1,(5))}$

goodness-of-fit of a model was considered to be. When the AIC differed considerably from SBC, the models with the closest fit were selected according to their parsimony. The AIC and SBC were calculated as shown in Formulas (4.4) and (4.5).

$$\text{AIC} = \text{T}\ln(SSE) + 2k \tag{4.4}$$

$$\text{SBC} = \text{T}\ln(SSE) + k\ \ln(T) \tag{4.5}$$

where $\ln(SSE)$ is the natural logarithm of the sum of squared errors; $\ln(T)$ is the natural logarithm of the total number of samples; k represents the total number of parameters requiring estimation. Finally, the finalized predictive model and formula derivation of each index is listed in Table 4.

The rates of data changes of the indices from 2009/Q2 to 2016/Q4 were calculated according to the time-series analysis of the dynamic trends of each index at different time points. Thus, each pair of indices had the same calculation and comparison criteria in the subsequent DNP analysis. The quarterly rate of change was calculated using the following formula:

$$X_{(t)} = \frac{T_3 + T_2 + T_1}{3} \tag{4.6}$$

where $X_{(t)}$ represents the mean of the index X in quarter t; T_1, T_2, and T_3 respectively represent the first, second, and final months of a specified quarter.

$$\Delta X_{(t)} = (X_t - X_{t-1})/X_{t-1} \tag{4.7}$$

where $\Delta X_{(t)}$ represents the rate of change in X in quarter t relative to the preceding quarter; $X_{(t)}$ represents the mean of X in quarter t; and X_{t-1} represents the mean of X in the preceding quarter. Table 5 lists the quarterly rates of change in each index; the rates of change from 2009/Q2 to 2014/Q4 were converted from the data, whereas those from 2015/Q1 to 2016/Q4 were projected using the prediction models.

4.5. *Verifying the DNPs*

There are two types of DNPs: data-oriented and expert-oriented. For the data-oriented DNP, the rate of change in each index was applied as the basis for comparing the index pairs and calculating their weights; for the expert-oriented DNP, the questionnaires were used to obtain scores from experts for each index. The results of the two types of DNP were compared.

Regarding the dependency among the indices in the DNP, the FDM questionnaire was employed to identify the interactive relationships among the transportation sustainability indices with the closest fit (Fig. 4). The interactive relationships were then implemented in the expert-oriented and data-oriented DNPs to obtain the weighting matrix of the internal dependency among the indices (W_2).

4.5.1. *Verifying the data-oriented DNP*

The data-oriented DNP was divided into three steps. First, the rates of changes in the indices were compared in pairs to determine the corresponding level of importance of each index in achieving the goal of city livability. Second, the indices with internal dependency were compared in pairs to determine the extent of internal dependency. Third, the assessment matrix derived from the paired comparison was multiplied by the weighted vector of each index to calculate the weight of each index under the goal of city livability. These steps were repeated to obtain the weights of each index at different time points (t).

4.5.1.1. Weights of the indices without considering their internal dependency ($\boldsymbol{w}_1$). The quarterly rates of change in each index in the same year were compared in pairs to obtain their weights without considering their internal dependency; the changes are represented as vector w_1. The formula of the paired comparison is expressed as follows:

$$w_1^{xy} = \left|\frac{\Delta_x}{\Delta_y}\right| \tag{4.8}$$

where w_1^{xy} represents the weight of the index X relative to index Y (without considering internal dependency); Δ_x and Δ_y respectively represent the amounts of changes in X and Y. For a simple comparison of the rates of changes in the two indices, Δ_x was divided by Δ_y, and the absolute value was obtained.

4.5.1.2. Index internal dependency weighting matrix ($\boldsymbol{W}_2$). In the data-oriented DNP, the quarterly rates of change in each index in the same year were employed to estimate the dependency among the indices. As shown in Formula (4.9), $W^2_{x\to xy}$ represents the dependency weight of X relative to Y when X is the control index; it also represents the effect of the rate of change in Y on the rate of change in X when X is the control index. Formula (4.10) indicates the effect of the rate of change in Y on the rate of change in X relative to the index Z when X is the control index.

$$W_2^{x\to xy} = \frac{|\Delta_x| + |\Delta_y|}{|\Delta_x|} \tag{4.9}$$

where $W_2^{x\to xy}$ represents the dependency weight of X relative to Y when X is the control index; $|\Delta_x|$ represents the rate of change in X; $|\Delta_y|$ represents the rate of change in Y.

$$W_2^{x\to yz} = \frac{|\Delta_x| + |\Delta_y|}{|\Delta_x|} \Big/ \frac{|\Delta_x| + |\Delta_z|}{|\Delta_x|} \tag{4.10}$$

where $W_2^{x\to yz}$ represents the dependency weight of Y relative to Z when X is the control index; $|\Delta_x|$, $|\Delta_y|$, and $|\Delta_z|$ respectively represent the rates of changes in X, Y, and Z.

4.5.1.3. Weights of the indices involving their internal dependency ($\boldsymbol{w}_C$). Formula $w_1 \times W_2 = w_c$ was employed to obtain the weights of the indices with internal dependency (w_c). Finally, the extent of change in the indices at different time points was used to calculate the changes in the weights of the indices over the 31 quarters (2009/Q2–2016/Q4).

4.5.2. *Verifying the expert-oriented DNP*

To compare the effectiveness of data-oriented and expert-oriented DNPs, a questionnaire survey was administered to experts. To maintain consistency between the two phases of analysis of the questionnaire survey, the same interviewees were recruited for the DNP and FDM questionnaire surveys. Because of the complexity in the questionnaires, only one expert each from the industrial, governmental, and academic sector was interviewed in the DNP survey. The expert-oriented DNP was divided into the following three steps:

4.5.2.1. Weights of the indices without considering their internal dependency ($\boldsymbol{w}_1$). The experts were asked to use the revised version of

Table 5
Quarterly rates of change in each index (2009–2016).

Quarter	Index A1	Index A2	Index B1	Index B2	Index C1	Index C2	Index C3
	Land Consumption in Transportation	Use of Public and Non-motor Vehicles	Congestion Severity	Government Investment on Transportation	Accessibility of the Public Transportation	Safety (Number of Vehicle Accidents/ 10,000 Vehicles)	Health Impact (Pollutant Standards Index)
2009/Q2	−0.00014	0.016678	−0.00097	0.0001	0.002176	−0.35714	0.264544
2009/Q3	−0.00014	0.044736	0.001461	0.0001	0.132447	0.111111	−0.24504
2009/Q4	−0.00014	0.055548	0.007778	−0.00557	0.001655	0.00001	0.047339
2010/Q1	0.009523	−0.03808	0.005306	0.123318	−0.00209	0.4	0.828113
2010/Q2	0.009523	0.025127	−0.0024	0.001996	0.002708	−0.28571	−0.08525
2010/Q3	0.009523	0.021078	0.003367	0.000996	−0.00536	0.2	−0.1135
2010/Q4	0.009523	0.127379	0.0001	−0.00597	0.071742	0.0001	0.010333
2011/Q1	−0.00072	−0.02405	0.0001	−0.0991	0.037016	0.083333	0.30533
2011/Q2	−0.00072	0.00624	−0.00048	0.0001	0.005353	−0.30769	0.125244
2011/Q3	−0.00072	0.029716	0.001439	0.0001	−0.00358	0.0001	−0.09557
2011/Q4	−0.00072	0.037139	0.001437	0.062222	0.000767	0.222222	0.026097
2012/Q1	−0.00072	−0.00792	−0.00096	0.051255	0.062727	0.090909	0.617223
2012/Q2	−0.00072	−0.00575	−0.00335	0.00199	0.003125	−0.33333	0.137489
2012/Q3	−0.00072	0.021678	0.001441	0.001986	−0.00065	0.125	−0.12375
2012/Q4	−0.00072	0.075976	0.00001	0.004955	0.002135	0.444444	−0.17258
2013/Q1	−0.00022	−0.03882	0.0001	0.002959	−0.0019	−0.30769	0.90125
2014/Q1	−0.00022	0.010233	0.00048	0.0001	0.005882	0.111111	0.058119
2014/Q2	−0.00022	0.021588	−0.01103	0.000983	0.007302	0.3	−0.11379
2014/Q3	−0.00022	0.090505	−0.01794	0.003929	0.033937	−0.07692	0.141851
2014/Q4	0.000228	−0.02243	−0.01185	0.024462	0.015659	−0.25	0.450459
2015/Q1	0.000228	−0.00671	−0.00999	0.0001	0.004436	0.222222	0.015621
2015/Q2	0.000228	0.006151	−0.00706	0.0001	−0.00365	0.090909	−0.02642
2015/Q3	0.000228	0.040128	0.0001	0.030564	0.042099	0.916667	−0.03836
2015/Q4	0.001971	0.119708	−0.00203	0.0470	0.015122	−1.8029	0.006177
2016/Q1	0.002826	0.017684	−0.00088	−0.00146	0.009373	0.019165	0.076426
2016/Q2	0.002562	0.010641	0.0001	0.0001	0.011091	0.023055	−0.02353
2016/Q3	0.002353	0.001858	0.0001	0.0001	0.011833	0.015753	0.0026
2016/Q4	0.002188	0.017705	0.0001	0.0001	0.0121	0.009308	0.017395

Note: All the values from 2009/Q2 to 2014/Q4 were calculated from the actual data.

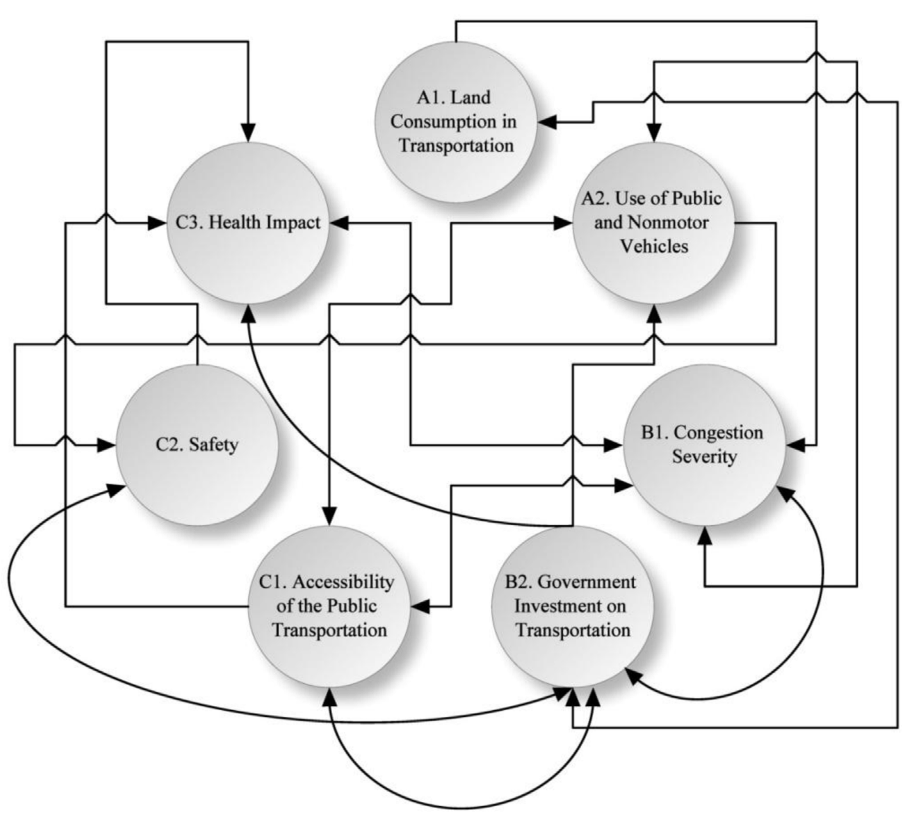


Fig. 4. Internal dependency among the indices.

the 1–9 scale created by Saaty (1990) to compare the seven indices in pairs, thereby obtaining the weightings of the indices without considering their internal dependency (w_1). Only those responses with consistency ratios lower than 0.1 in the matrix of a paired comparison were considered to satisfy the consistency test.

4.5.2.2. Index internal dependency weighting matrix (W_2). The experts assessed how each control index was affected by the other indices that exhibited internal dependency according to the extent of their influence. The following two conditions must be fulfilled: (a) the self-importance of each index was equal (importance = 1); (b) when a control index was present, the control index has higher importance than the other indices do (importance > 1). Although internal dependency was observed among the indices, the self-importance of the control index was higher than those of the other indices. The level of internal dependency among the indices (W_2) was calculated according to the FDM questionnaire survey results.

4.5.2.3. Weights of the indices involving their internal dependency (w_C). The formula $w_1 \times W_2 = w_c$ was used to calculate the weights of the indices with internal dependency (w_c). Finally, the extent changes in the indices at different time points was used to calculate the changes in the weights of the indices at three time points, namely in 2009, in 2013, and in 2016.

4.5.3. Comparing the empirical results of the two DNPs

Table 6 and 7 and Fig. 5 illustrate the changes in the weights of the transportation sustainability indices in the data-oriented DNP. Land consumption in transportation (Index A1) remained the lowest-weighted from 2009 to 2016, with no significant change in its trend. The weight of the use of public and non-motor vehicles (Index A2) gradually increased before progressively decreasing; the weight was the third to fifth highest. The weight of congestion severity (Index B1) gradually decreased before progressively increasing; this weight was the second to fifth highest. The weight of government investment on transportation (Index B2) gradually increased and remained the highest from 2009 to 2016. The weight of government investment in transportation (Index C1) gradually decreased before progressively increasing; this weight was the third to fifth highest, exhibiting the similar trend to Index B1. The weight of safety (Index C2) gradually increased before progressively decreasing; this weight was the second to fifth highest for the majority of the period. The weight of health impact (Index C3) gradually decreased, remaining the second lowest throughout the study period. To further clarify the trends and compare them to the results of the conventional DNP, the quarterly weight changes were converted to annual weight changes, as shown in Table 8 and Fig. 6.

On the expert-oriented DNP, the questionnaire responses were used to calculate the weight changes in the transportation sustainability indices for Taipei City according to the responses of each expert. The geometric mean of the responses from the experts of the industrial, governmental, and academic domains was calculated for the equal considerations of the three domains, thereby revealing the dynamic weight changes and sequential order, as shown in Table 9 and Fig. 7

The weight of Index A1 remained relatively stable and was the fourth or fifth highest for most of the study period. The weight of Index A2 gradually increased from third highest in 2009 to the highest in 2016. The weight of Index B1 remained fifth or sixth highest overall. Index B2, which maintained the highest weight in 2009–2013 and was third highest in 2016, was a vital index for transportation sustainability. Index C1 maintained the second highest weight throughout the study period. The weight of Index C2 decreased to sixth before recovering to fourth. Index C3 maintained the lowest weight throughout the study period with no significant change in its sequential order.

To further compare the results of the expert-oriented and data-oriented DNP, the data-oriented DNP calculation results from 2009 to 2016 were integrated into the 2009, 2013, and 2016 data through their geometric means. Subsequently, the comparison results were organized into a weight sequence chart (Table 10.) and a dynamic index trend comparison chart (Table 11).

Regarding the sequencing results shown in Table 10., Index B2 was the most critical index in both the data-oriented and expert-oriented DNPs, and Index A2 also exhibited considerable importance. By contrast, Index C3 was regarded as the least critical index. The difference between the two DNPs was the most significant for Index C1, the weight of which was fifth highest in the data-oriented DNP and second highest in the expert-oriented DNP.

Significant differences were observed between the two DNPs in their prediction of future trends in the indices. As revealed in Table 11, the weight of Index A1 increased before decreasing in the expert-oriented DNP, but decreased slightly before increasing in the data-oriented DNP. The weight of Index A2 continually increased in the expert-oriented DNP, but decreased after peaking in the data-oriented DNP. The weight of Index B1 remained relatively steady in the expert-oriented DNP, but it decreased substantially before increasing in the data-oriented DNP. The weight of Index B2 continually decreased in the expert-oriented DNP, but continually increased in the data-oriented DNP. The weight of Index C2 increased slightly before decreasing and remaining relatively constant in the expert-oriented DNP, but decreased substantially before increasing in the data-oriented DNP. The weight of Index C2 exhibited a profound decrease before increasing in the expert-oriented DNP, but it increased significantly before decreasing in the data-oriented DNP. Finally, the weight of Index C3, which exhibited the smallest difference between the two DNPs, remained relatively constant in both the DNPs. However, some slight differences could still be identified. The weight of Index C3 gradually increased in the expert-oriented DNP, but slowly decreased in the data-oriented DNP.

In summary, the expert-oriented and data-oriented DNPs were similar in parts of the weighting sequences and trend estimation, but significant differences were observed in most of the index analysis results. This was attributed to subjective opinions of the experts, who may have overlooked the complexity of the problems facing Taipei City. This might also be because the data selected in this study were not ideal for estimation. Consequently, some of the data could not thoroughly reflect the conditions as predicted by the experts; some of the indices involve numerous data and might be affected by factors that are difficult to quantify. However, because the goal of this study was to assess the transportation sustainability indices and strategies for attaining high

Table 6
Quarterly changes in the weights of the indices in the data-oriented DNP (2009Q2–2012Q4).

w_c	2009 Q2	2009 Q3	2009 Q4	2010 Q1	2010 Q2	2010 Q3	2010 Q4	2011 Q1	2011 Q2	2011 Q3	2011 Q4	2012 Q1	2012 Q2	2012 Q3	2012 Q4
A1.	0.001	0.001	0.031	0.033	0.014	0.015	0.030	0.056	0.001	0.005	0.058	0.023	0.004	0.005	0.003
A2.	0.187	0.130	0.128	0.106	0.235	0.194	0.192	0.084	0.233	0.060	0.238	0.063	0.232	0.157	0.218
B1.	0.101	0.197	0.203	0.139	0.067	0.094	0.267	0.166	0.073	0.212	0.054	0.184	0.071	0.121	0.087
B2.	0.290	0.275	0.215	0.225	0.316	0.307	0.275	0.191	0.307	0.222	0.262	0.208	0.303	0.280	0.306
C1.	0.100	0.141	0.238	0.168	0.068	0.092	0.200	0.182	0.069	0.205	0.111	0.176	0.072	0.125	0.088
C2.	0.228	0.149	0.098	0.200	0.249	0.222	0.023	0.196	0.251	0.148	0.255	0.188	0.250	0.210	0.239
C3.	0.093	0.106	0.088	0.130	0.050	0.075	0.012	0.125	0.066	0.147	0.023	0.158	0.067	0.101	0.058

Table 7
Quarterly changes and sequential order of the weights of the indices in the data-oriented DNP (2013Q1–2016Q4).

w_c	2013Q1	2013Q2	2013Q3	2013Q4	2014Q1	2014Q2	2014Q3	2014Q4	2015Q1	2015Q2	2015Q3	2015Q4	2016Q1	2016Q2	2016Q3	2016Q4
A1.	0.001	0.001	0.007	0.020	0.017	0.009	0.013	0.012	0.009	0.017	0.018	0.035	0.019	0.019	0.035	0.033
A2.	0.084	0.206	0.228	0.122	0.120	0.296	0.241	0.300	0.308	0.079	0.149	0.236	0.132	0.150	0.166	0.126
B1.	0.160	0.098	0.073	0.174	0.142	0.024	0.062	0.037	0.021	0.190	0.167	0.129	0.214	0.236	0.235	0.223
B2.	0.244	0.304	0.311	0.284	0.247	0.329	0.318	0.316	0.324	0.257	0.306	0.321	0.300	0.298	0.312	0.277
C1.	0.160	0.086	0.078	0.162	0.148	0.031	0.072	0.029	0.025	0.165	0.120	0.096	0.152	0.170	0.160	0.155
C2.	0.198	0.230	0.242	0.146	0.198	0.290	0.242	0.294	0.311	0.164	0.161	0.161	0.113	0.078	0.061	0.100
C3.	0.152	0.074	0.061	0.092	0.128	0.021	0.053	0.012	0.002	0.128	0.079	0.023	0.070	0.050	0.032	0.087

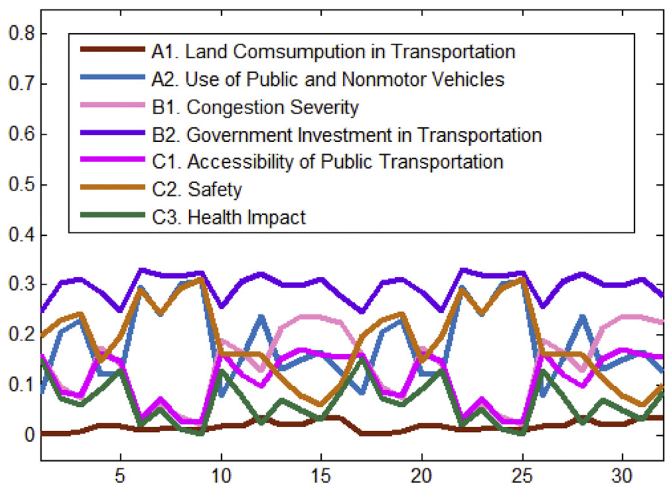


Fig. 5. Line chart showing the quarterly changes in the weights of the indices in the data-oriented DNP.

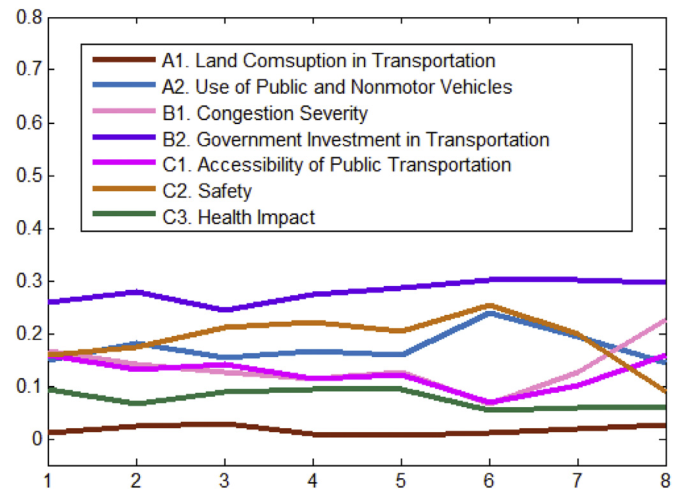


Fig. 6. Line chart showing the annual changes in the weights of the indices in the data-oriented DNP.

livability in Taipei City through the use of the data-oriented DNP, the follow-up suggestions on sustainable transportation strategies were still based on the data-oriented DNP analysis results.

4.6. Sustainable transportation strategies to fulfill the livability of Taipei City

The sustainable transportation strategies that fulfill the livability of Taipei City were formulated according to the analysis results. The orientations of the sustainable transportation strategies in other cities were reviewed as references for revising the transportation strategies in Taipei. Subsequently, the dynamic changes in the index weights were analyzed to generalize the future developmental trend of the transportation in Taipei City. Finally, discussions and suggestions were made on the *2020 White Paper on the Transportation Policies in Taipei.*

4.6.1. Referencing urban transportation strategies

To properly and effectively develop urban transportation, city governments have proposed transportation plans that are suitable for their respective cities, formulated the vision of those plans, and extended their durations to 2020, 2040, or even into the second half of the century. The transportation dimension of the 2010 Greater London Plan involved six primary strategic goals: support economic and population growth, strengthen the quality of daily living, improve safety and privacy, improve transportation accessibility, reduce the effect of transportation on climate change and improve transportation flexibility, and support the 2012 London Olympics and Paralympics. In addition, developmental strategies were established to support the six

Table 9
Annual changes and sequential order of the index weights according to the expert opinions.

w_C	2009	Order	2013	Order	2016	Order
A1. Land Consumption in Transportation	0.1172	5	0.1600	4	0.1431	4
A2. Use of Public and Non-motor Vehicles	0.1427	3	0.1645	3	0.2002	1
B1. Congestion Severity	0.1133	6	0.1279	5	0.1164	6
B2. Government Investment in Transportation	0.2723	1	0.2326	1	0.1696	3
C1. Accessibility of Public Transportation	0.1963	2	0.2158	2	0.1882	2
C2. Safety	0.1289	4	0.0729	6	0.1391	5
C3. Health Impact	0.0290	7	0.0260	7	0.0431	7

Table 8
Annual changes and sequential order of the weights of the indices in the data-oriented DNP (2009–2016).

w_c	2009	Order	2010	Order	2011	Order	2012	Order	2013	Order	2014	Order	2015	Order	2016	Order
A1	0.011	7	0.023	7	0.030	7	0.009	7	0.007	7	0.012	7	0.019	7	0.026	7
A2	0.148	5	0.182	2	0.153	3	0.167	3	0.160	3	0.239	3	0.193	3	0.143	4
B1	0.166	2	0.141	4	0.126	5	0.115	4	0.126	4	0.066	5	0.126	4	0.226	2
B2	0.260	1	0.280	1	0.245	1	0.274	1	0.286	1	0.302	1	0.302	1	0.296	1
C1	0.159	3	0.132	5	0.141	4	0.115	5	0.121	5	0.070	4	0.101	5	0.159	3
C2	0.158	4	0.173	3	0.212	2	0.222	2	0.204	2	0.255	2	0.199	2	0.088	5
C3	0.095	6	0.066	6	0.090	6	0.095	6	0.094	6	0.053	6	0.058	6	0.059	6

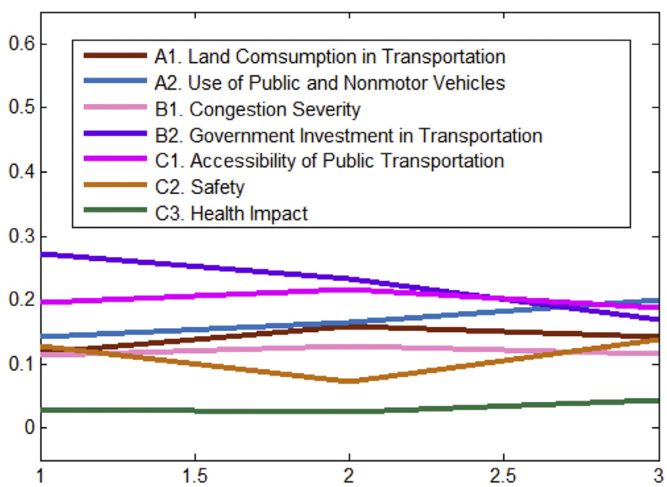


Fig. 7. Line chart showing the time-dependent weight changes in the indices in the expert-oriented DNP.

goals. The Transportation 2040 Plan, established to improve land use and transportation coordination in Puget Sound, involves the following practical design principles: (a) promote mixed land use; (b) arrange residential areas to promote high-density residential growth; (c) connect neighborhoods with streets, alleys, and sidewalks; (d) integrate the activity spaces of surrounding communities; (e) establish semipublic or public high-capacity transit stations near the centers of specified cities; (f) design plans for pedestrians and bicycles; (g) provide citizens with open spaces; (h) manage parking spaces; (i) improve the advantages of street parking; and (j) reduce the negative effects of parking. The Southeast Michigan Council of Governments established their *Principles Guiding Development of the 2040 Regional Transportation Plan*, which are described as follows: (a) emphasize construction on numerous regional assets and provide strategic investments in local- and regional-scale projects under finite financial resources; (b) disclose information pertaining to transportation to the public; (c) improve the comprehensiveness of transportation systems; (d) strengthen various modes of travel and the connection among local residents, communities, and global society; (e) enhance the flexibility and adaptability of transportation in response to environmental dynamics; (f) provide various groups with a cooperation framework; and (g) coordinate the plan with other projects such as macroeconomic development strategies, sustainability frameworks, residential strategies, environmental plans, and green infrastructures. The goals of the 2040 Regional Transportation Plan by the Houston–Galveston Area Council were aimed at improving safety, reducing congestion, safeguarding ideal asset management and operations, strengthening regional economic competitiveness, and conserving and protecting natural and cultural resources. These goals correspond to four strategies: improving system management and operations, improving the states of ideal maintenance, expanding the multimodal network, and coordinating development. Finally, the effectiveness of the strategies is examined through the use of relevant assessment indices.

In response to climate change, Santos and Ribeiro (2013) proposed the following transportation strategies for Rio de Janeiro: (a) expand the railway and subway network; (b) expand the bus rapid transit system; (c) improve sustainable bio-fuel; (d) enforce bus plans; (e) promote the use of electric vehicles; (f) implement light vehicle inspection and maintenance plans; and (g) formulate vegetable oil and biodiesel reuse plans. Shiau (2012) formulated 15 sustainable transportation strategies for Taipei City and determined their priority. In particular, improving the accessibility of non-motorized transportation modes, the use of biodiesel and bio-gasoline, demand responsive transport services, and accessibility of transportation to elderly people and people with disabilities are four of the five highest-priority strategies.

In summary, most transportation strategies formulated worldwide have involved the following aspects: (a) accessibility, promotion, and construction of public transportation; (b) friendliness, safety, and quality of daily living; (c) traffic management; (d) maintenance of related assets; (e) protection of natural resources; (f) responses to climate change; (g) improvement of system flexibility. Some strategies have been associated with the disclosure of government information, land use and urban plans, or master land use plans. Similarly, most of the contents of the *2020 White Paper on the Transportation Policies in Taipei* focused on public transportation, friendliness, safety, quality of daily living, and traffic management. However, few strategies on maintaining assets, responding to climate change, disclosing government information, and linking transportation plans with urban development plans have been proposed by the Taipei City Government. The disclosure of government information has been regarded only as a subtopic in smart transportation. The association of transportation plans with urban planning is barely notable in strategies for constructing an environment that is comfortable, obstacle-free, and beneficial for developing public transportation. No consideration has been given to maintaining assets and responding to climate change.

4.6.2. Future contexts and strategies for the transportation in Taipei City

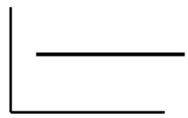
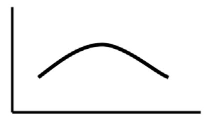
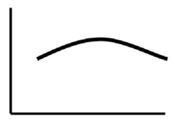
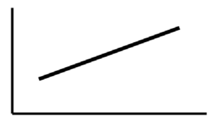
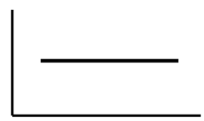
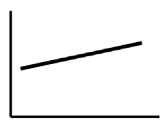
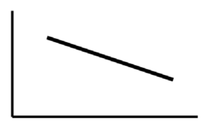
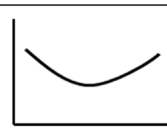
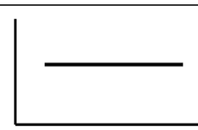
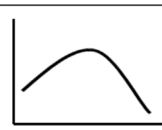
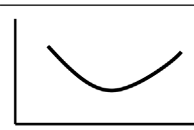
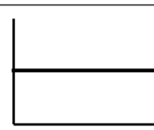
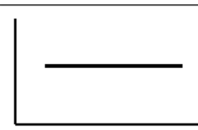
The goal of this study was to assess the transportation sustainability indices and strategies for Taipei City to achieve the goal of livability. Therefore, the follow-up suggestions of transportation planning were based on the data-oriented DNP analysis results. According to the aforementioned index analysis results, the future conditions of transportation in Taipei City were analyzed, and suggestions were proposed on the *2020 White Paper on the Transportation Policies in Taipei*. The future conditions regarding the transportation plans in Taipei were analyzed as follows:

(a) No significant changes in the land consumption and use in transportation were observed. This was ascribed to the status of Taipei City as a high-density development zone, with land use approaching saturation. Although the Taipei MRT network continues to under development, most developments have occurred in the New Taipei City areas surrounding Taipei City. Nearly all of the

Table 10
Weight sequence results of the data-oriented and expert-oriented DNPs.

w_C	2009		2013		2016	
	Data	Conventional	Data	Conventional	Data	Conventional
A1. Land Consumption in Transportation	7	5	7	4	7	4
A2. Use of Public and Non-motor Vehicles	3	3	3	3	3	1
B1. Congestion Severity	4	6	4	5	2	6
B2. Government Investment in Transportation	1	1	1	1	1	3
C1. Accessibility of Public Transportation	5	2	5	2	5	2
C2. Safety	2	4	2	6	4	5
C3. Health Impact	6	7	6	7	6	7

Table 11
Weighting sequences in the data-oriented and expert-oriented DNPs.

Index	Data-Oriented DNP	Expert-Oriented DNP	Comparative Analysis
	Schematic Map	Schematic Map	
A1. Land Consumption in Transportation			Nonsignificant difference
A2. Use of Public and Non-motor Vehicles			Significant difference
B1. Congestion Severity			Significant difference
B2. Government Investment in Transportation			Significant difference
C1. Accessibility of Public Transportation			Significant difference
C2. Safety			Significant difference
C3. Health Impact			Similar

land in Taipei City has been used in planning and construction; undeveloped zones have not change substantially in their number because of problems in acquiring reserved land. Therefore, little concern is required for Index A1 (land consumption in transportation) in current transportation plans for Taipei City.

(b) The weight of Index A2 (use of public and non-motor vehicles) peaked in 2013. In 2009–2013, numerous MRT lines were opened, and the construction of public bicycle stations was expanded, exceeding 100 in 2013. Hence, the rate of the use of public and non-motor vehicles peaked in that year. Although the weight of A2 decreased slightly in 2016, this index remains among the most prioritized indices. Therefore, Index A2 should receive considerable attention in transportation planning. Substantially associated to Index A2 is Index C1 (accessibility of the public transportation). Therefore, Index C1 should also be highly prioritized in transportation planning. According to the status of Index A1, the construction of additional MRT stations may be limited by land conditions. Therefore, decision makers should increase the use of public and non-motor vehicles through other dimensions and improve their accessibility without increasing land use.

(c) The weight of Index B1 (congestion severity) continually increased over time. This is attributable to the increasing prevalence of public and non-motor vehicles. Index B2 (government investment in transportation) was consistently the highest-weighted index throughout the specified years; not only has its weight changed considerably, but it has had also profound effected on the other index weights.

(d) The weight of Index C2 (safety) has been one of the highest in the overall weighting sequence. Although its weight has dropped more recently, it has remained highly crucial for transportation planning in Taipei City. This reveals that the urban transportation safety pertaining to roads, sidewalks, and bicycle lanes must continue to receive consideration in future transportation strategies for Taipei City. Index C3 (health impact) has remained among the indices with the lowest weights. Because the applied data corresponding to the index was the air pollution index, the air quality in Taipei City was considered stable and acceptable. Therefore, improving this index would not substantially affect the overall quality of transportation in Taipei City. This index does not require attention in the short term.

4.6.3. Suggestions for the 2020 white paper on the Transportation Policies in Taipei

The general orientation of the transportation strategies for Taipei City was clarified through the situational analysis based on the index weighting results. The analysis results correspond to the suggestions for the urban transportation planning in Taipei City in the *2020 White Paper on the Transportation Policies in Taipei*.

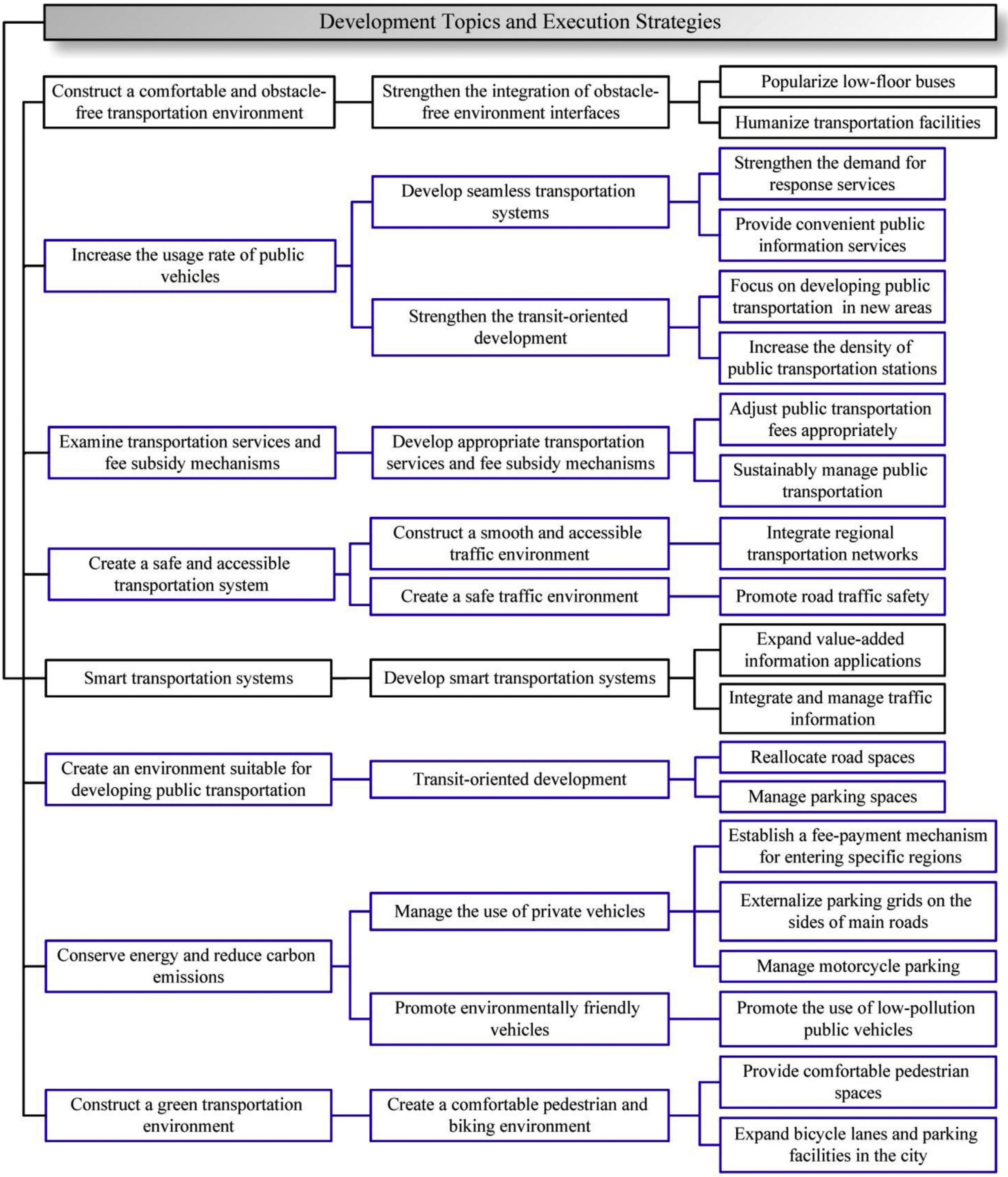


Fig. 8. Development topics and execution strategies in the 2020 White Paper on Transportation Policies in Taipei. Source: Department of Transportation, Taipei City Government.

This white paper lists sustainable transportation, affinity and humanism, and livability and safety as the visions of development. Corresponding to the visions are four specific development goals: increase the usage rate of environmentally friendly vehicles to 70%, fully implement low-pollution public transportation vehicles in the city, strengthen obstacle-free environments, and reduce the rate of traffic accidents by 3% annually. Numerous execution strategies (Fig. 8) were formulated on the basis of the following dimensions:

(a) Establish a comfortable and obstacle-free transportation environment
(b) Increase the usage rate of public transportation
(c) Examine transportation services and fee subsidy mechanisms
(d) Create a safe and accessible transportation system
(e) Promote smart transportation systems
(f) Create an environment suitable for developing the public transportation network

(g) Conserve energy and reduce carbon emissions (i.e., fossil fuel usage and motor vehicle emissions)
(h) Construct an environmentally friendly transportation environment

The four development goals of the white paper correspond to the results of the analysis of the index weights. Index A2 (use of public and non-motor vehicles) accords with the goal of introducing low-pollution public transportation vehicles, and Index C2 (Safety) accords with the goal of reducing the rate of traffic accidents. In the index weight dynamic analysis, both of these indices were among those with the highest priority. Therefore, the development goals of introducing low-pollution public transportation vehicles and reducing the rate of traffic accidents should be prioritized over increasing the usage rate of environmentally friendly vehicles and improving obstacle-free environments.

On the overall transportation development in the city, increasing the usage rate of public transportation, examining the transportation services and fee subsidy mechanisms, creating a safe and easy-to-understand transportation system, conserving energy and reducing carbon emissions, creating an environment suitable for developing public transportation, and constructing an environmentally friendly transportation environment are consistent with the assessment dimensions generalized in this study and should be prioritized as strategic dimensions for developing sustainable transportation in Taipei City. Regarding establishing comfortable and obstacle-free transportation environments and promoting smart transportation systems, two related indices were disregarded in the FDM phase of the index assessment, because they are the lowest-priority dimensions for the sustainable transportation development. For easy distinction, Fig. 8 displays the strategic dimensions and strategies consistent with the weight analysis results colored in yellow and orange (the other dimensions and strategies are temporarily disregarded).

On the correspondence between the indices and strategies (Fig. 9), managing parking spaces, establishing a fee-payment mechanism for vehicles entering specific regions, and externalizing parking grids on the sides of the main roads correspond to Index B1 (congestion severity). Increasing the number of bicycle lanes and parking facilities in the city, promoting the density of public transportation stations, and promoting public-transportation-oriented development in newly developed regions correspond to the highly weighted Index C1 (accessibility of public transportation) and must be prioritized in the development strategies. Strengthening the demand for response services, rationalizing public transportation fees and sustainably managing public transportation, and providing comfortable pedestrian spaces correspond to the highly weighted Index A2 (use of public and non-motor vehicles), and promoting road traffic safety corresponds to the similarly weighted Index C2 (safety). These strategies must be prioritized. Integrating regional transportation networks, reallocating road spaces, and promoting low-pollution public vehicles correspond to the low-weight Indices A1 (land consumption in transportation) and C3 (health impact) and are thus low-priority strategies. Popularizing low-floor buses, humanizing transportation facilities, expanding value-added information applications, integrating and managing traffic information, and providing convenient public information services do not correspond to any of the indices examined in this study. Therefore, these strategies are lowest-priority in promoting sustainable transportation in Taipei City.

5. Policy implication and conclusion

This section summarizes the analysis results, namely the preliminary generalization and selection of the indices, results of the data-oriented DNP, and comparison between the data- and expert-oriented DNPs. In addition, from the data-oriented DNP results, suggestions for the Taipei City Government regarding the white paper on transportation policies in Taipei City are offered.

(a) **Aggregating the transportation sustainability indices:** Previous studies on livable cities and sustainable transportation (Section 2) were generalized to derive 18 indices along three dimensions (environmental, economic, and social).
(b) **Selecting the indices applicable for attaining the livability of Taipei City:** From the preliminary list of transportation sustainability indices that satisfy the principles of a livable city, the first-phase FDM expert questionnaire survey was performed. Six experts with industrial, governmental, and academic backgrounds in transportation were invited to evaluate the indices. The threshold value for FDM selection was 7.30; seven critical indices were above this threshold.
(c) **Data-oriented DNP results:** The rates of changes in the indices were implemented in the DNP to obtain the quarterly weight changes in the indices in 2009–2016. The weights of Index A1 were 0.1172, 0.1600, and 0.1431 in 2009, 2013, and 2016, respectively. The weight non-significantly increased before decreasing over the years. Therefore, the function of the index is $d_1t^2 + d_2t + d_3$ (d_1 is negative). The index had the lowest weight of the seven selected indices. The corresponding weights for Index A2 were 0.1427, 0.1645, and 0.2002. This index was initially among the top three indices but became the top-priority index in 2016, increasing in a linear manner. Therefore, the function of the index is $a_1t + a_2$ (a_1 is positive). The corresponding weights of Index B1 were 0.1133, 0.1279, and 0.1164. No significant changes were observed in the weight of the index or its priority. Therefore, the constant a, which did not change over time, was used to interpret the index. The respective weights of Index B1 were 0.2723, 0.2326, and 0.1696. Because the weight of this index decreased steadily and linearly over time, the function of the index is $a_1t + a_2$ (a_1 is negative). The overall priority of this index was the third-highest in 2016. The corresponding weights of Index C1 were 0.1963, 0.2158, and 0.1882. No significant changes were observed in the weight of the index or its priority. Therefore, the constant a, which did not change over time, was used to interpret the index. The respective weights of Index C2 were 0.1289, 0.0729, and 0.1391. This index was one of three highest-priority indices over the study period. Because the weight of this index initially decreased and then increased over time, the function of this index is $d_1t^2 + d_2t + d_3$ (d_1 is positive). The corresponding weights of Index C3 were 0.0290, 0.0260, and 0.0431. No significant changes were identified in the weight of the index and its priority. Therefore, the constant a, which did not change over time, was used to interpret the index.
(d) **Comparison of the data- and expert-oriented DNPs:** The sequencing results of the two DNPs show that Index B2 was the most critical index in both DNPs, Index A2 also exhibited considerable importance, and Index C3 was the least critical. The most notable difference between the two DNPs was in Index C1, which was the fifth highest-weighted in the data-oriented DNP but second in the expert-oriented DNP. Significant differences between the two DNPs were also noted regarding their prediction of the future trends of the indices. As shown in Table 11, the weight of Index A1 increased before decreasing in the expert-oriented DNP, but it decreased slightly before increasing in the data-oriented DNP. In the expert-oriented DNP, the weight of Index A2 continually increased, but it decreased after increasing in the data-oriented DNP. The weight of Index B1 remained relatively constant in the expert-oriented DNP, but it decreased substantially before increasing in the data-oriented DNP. In the expert-oriented DNP, the weight of Index B2 continually decreased, but the opposite trend was observed in the data-oriented DNP. The weight of Index C2 slightly increased before decreasing or remaining relatively constant in the expert-oriented DNP, but a substantial decrease was observed before an increase in the data-oriented DNP. The weight of Index C2 profoundly decreased before increasing in the expert-oriented DNP, yet the opposite was observed in the data-oriented DNP. Finally, the weight of

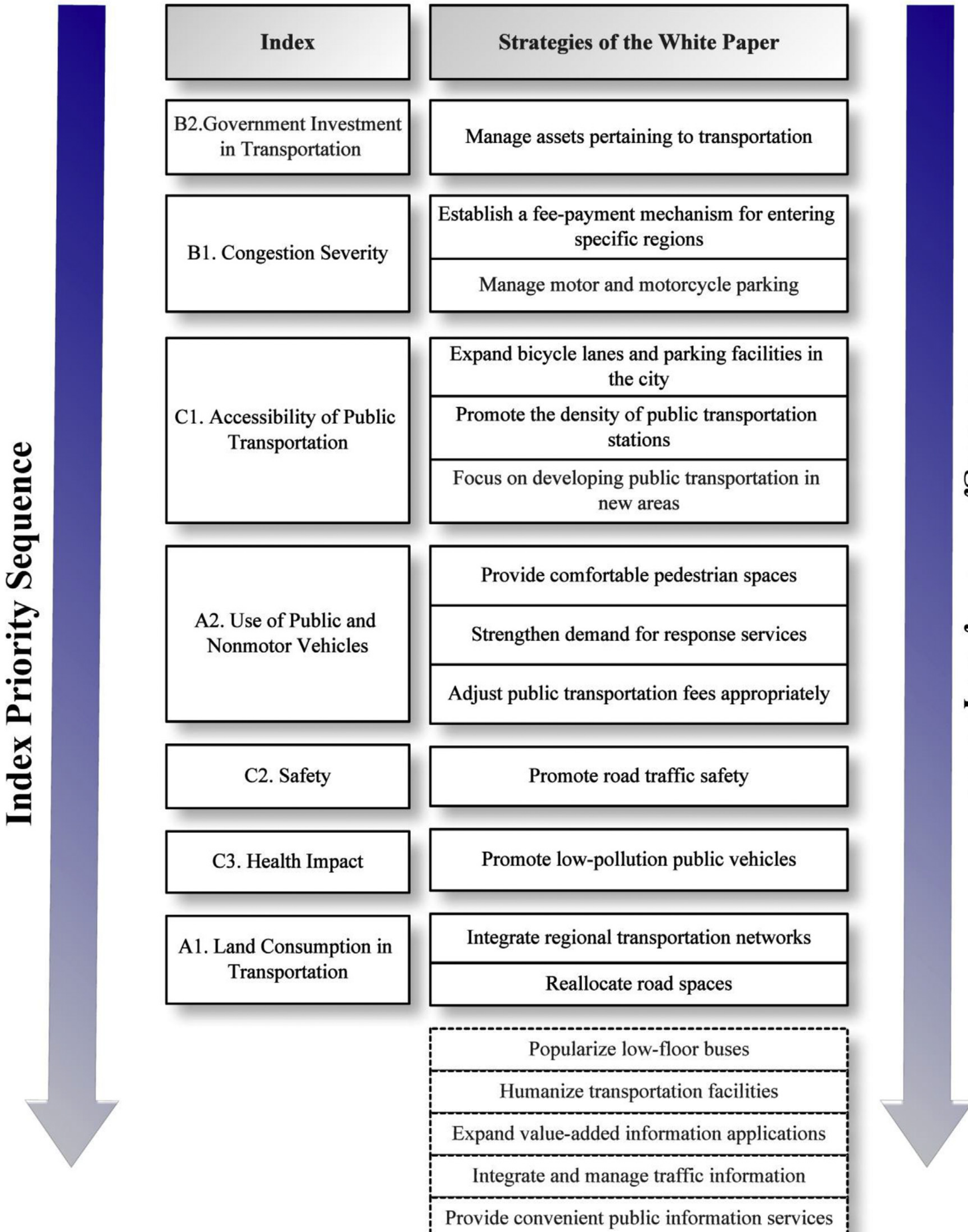


Fig. 9. Priority sequence of the execution strategies in the 2020 White Paper on Transportation Policies in Taipei.

Index C3, which exhibited the smallest difference between the two DNPs, remained constant throughout the study period in both the DNPs. However, some slight differences were identified. The weight of Index C3 gradually increased in the expert-oriented DNP, but the opposite was observed in the data-oriented DNP.

(e) **Suggestions for the white paper on the transportation policies in Taipei City according to the dynamic trends of the index weights:** Regarding the four development goals listed in the *2020 White Paper on the Transportation Policies in Taipei*, the dynamic analysis of the index weights shows that Indices A2 and C2 are among the highest-priority indices. Therefore, the two goals of introducing low-pollution public transportation and reducing the rate of traffic accidents should be regarded as the most critical goals.Regarding the execution of the strategies, the management of parking spaces, establishment of a fee-payment mechanism for the vehicles entering specific regions, and externalization of parking grids to the sides of the main roads correspond to Index B1 (congestion severity). Increasing the number of bicycle lanes and parking facilities in the city, promoting the density of public transportation stations, and focusing on the development of public transportation systems in newly developed regions correspond to the highly weighted Index C1 (accessibility of public transportation) and must be prioritized as development strategies. Strengthening the demand for response services, rationalizing public transportation fees, sustainably managing public transportation, and providing comfortable pedestrian spaces correspond to the highly weighted Index A2 (use of public and non-motor Vehicles), and promoting road traffic safety corresponds to Index C2 (safety), which was similarly weighted. These strategies must be prioritized. Integrating regional transportation networks, reallocating road spaces, and promoting low-pollution public vehicles correspond to the low-weight Indices A1 (land consumption in transportation) and C3 (health impact), both of which are low-priority strategies. Popularizing low-floor buses, humanizing transportation facilities, expanding value-added information applications, integrating and managing traffic information, and providing convenient public information services did not correspond to any of the indices investigated in this study. Therefore, these strategies should be considered the lowest-priority strategies in promoting the sustainable transportation in Taipei City. The *2020 White Paper on the Transportation Policies in Taipei* focused on public transportation, friendliness, safety, quality of daily living, and traffic management, similar to urban development strategies in most cities. However, the Taipei City Government has proposed few strategies on maintaining assets, responding to climate change, disclosing government information, and associating transportation planning with urban development planning. The disclosure of government information has been regarded as only a subtopic in the development of smart transportation systems. The association of transportation planning with urban planning is barely notable in strategies aimed at constructing an environment that is comfortable, obstacle-free, and beneficial for developing public transportation. No consideration has been attached to maintaining assets and responding to climate change.

Here, we must make a brief declaration that this study does not involve any emerging technology or new hardware architecture (Alam, Mehmood, Katib, Albogami, & Albeshri, 2017; Arfat et al., 2017; Rashid, Royston, Gary, Patrick, & Mukesh, 2017), nor does it involve any personal information from emerging technology users. The focus of this study is to return to the essence of urban development with dynamic perspective that toward realistic urban situations. And, for achieving ultimate goal of urban sustainability and urban livability (Yigitcanlar and Teriman, 2015), we expect to formulate a more transparent and realistic urban development strategies that incorporate only few concise tools and materials, including Fuzzy Delphi method, extendible open data (i.e., big data), auto-regressive integrated moving average model and Analytic Network Process. Unlike the previous ANP or AHP studies that focus on converting qualitative information into quantitative parameters (Wey & Chiu, 2013; Chan, Wey & Chang, 2014), in this study, we firstly attempt to integrate the dynamic changes of extendible open data (big data) and ANP mechanisms to address quantitative issues directly. In other words, our main innovation not only reveals the dynamic weight changes in data-oriented ANP, but also expresses the dynamic concept of indices or alternatives that change over time. Surely, the emerging technologies, industry-driven mechanisms, intelligent systems or any ICT-based hardware (e.g., autonomic systems, self-driving vehicles, cloud computing, mobile big data fogs, internet of things, and distributed systems) that were not covered in this study still worth to be considered in further to promote the three priority development goals (i.e., smart growth; sustainable growth, inclusive growth) that set by European Union (Schlingensiepen et al., 2016). Finally, we reiterate that the policy implications of this study may offer a solution for current needs related to urban planning in the whole world, especially in developing cities, and may serve as a more transparent decision-making or selection basis for developing sustainable and livable urban life in near future.

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