JOURNAL OF H&T
www.johat.org

Travel, Transportation, and Data Management: Implementations of Geographical Information Systems (GIS)

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Abstract : Logistic travel routs and effective transportation systems are vital for tourism industries. Despite the wide adoption of Geographical Information System (GIS) techniques to analyze issues in the travel and transportation sector, few studies have been done to investigate levels of GIS applications in individual states' Departments of Transportation (DOTs). To fill this void, this study evaluated the usages of GIS techniques in ten southeastern state DOTs (including Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee, Virginia, and West Virginia). Comparisons were conducted across the studied ten state DOTs in terms of the existence of GIS department/division, GIS applications, and data management. Similarities and differences regarding levels of GIS techniques were identified for the studied region.

Keywords: Transportation, Data Management, Geographical Information System

1. Introduction

The Geographical Information System (GIS) was established in the early 1960s and has been developed and advanced rapidly since the late 1980s (Hao et al., 2014). GIS is defined as a system used to manage geographic data, perform geographic analyses, and illustrate geographic relationships and patterns spatially (Shaw, 2016). GIS makes contributions to infrastructure planning, spatial logistic analyses, thematic visual accesses, various decision supports, and layers of data management (Miller and Shaw, 2015). The merits of utilizing GIS techniques have been well noted by a wide range of sectors (e.g., public, voluntary, and private organizations and stakeholders) over the past 50 years.

In the travel and transportation sector, GIS has been utilized to analyze travel and transportation-related issues. Departments of Transportation, led by the U.S. Federal Government and individual state governments, have always been one of the most important domains of GIS applications in the transportation sector. Departments of Transportation (DOTs) have applied GIS technologies to a variety of transportation areas, including pavement management, bridge management, safety management, transportation system management, travel demand forecasting, construction management, accident analysis, environment impact assessments, and land-related analyses (Fletcher, 2000). Although the majority of state DOTs have adopted GIS technologies, the levels of maturity and penetration are inconsistent across U.S. states. For example, some states have adopted GIS in their various transportation projects on a daily basis, while a few states are still becoming familiar with the functions and benefits of using GIS technologies.

Numerous benefits have been obtained from implementing GIS techniques while supporting the major strategic goals of Departments of Transportation. Through using GIS technologies, many transportation-related projects and tasks have been more effectively and efficiently handled, streamlining the decision-making process for DOTs. GIS house information-sharing facilitates the communication process in various ways such as providing visually attractive and understandable thematic maps, as well as offering more user-friendly channels to enable the public to retrieve and understand needed information (FWHA, 2017). Therefore, increasing the use of GIS may assist State DOTs in realizing further benefits in terms of efficiency and budget allocations.

The main purpose of this study is to investigate the levels of GIS applications in Departments of Transportation in the southeastern region of the U.S (including Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee, Virginia, and West Virginia). In this study, ten states' GIS applications and adoptions are evaluated based on data availability and the depth of GIS adoption. Based on the obtained information and comparisons across ten state DOTs, valuable information and further recommendations were presented to the Departments of Transportation.

2. Related work

2.1 Measure GIS applications

Despite the extended history of usage of GIS in many sectors like government, the transportation sector, the commercial sector, etc., it is still difficult to measure and quantify the level of GIS applications owing to the rapid updates of spatial systems and not yet fully realized and explored GIS advanced techniques (Alrwais et al., 2015). However, many scholars (Grimshaw, 1996, Turner and Higgs, 2003, Van Loenen and van Rij, 2008, Abdulaal, 2009, Kurwakumire, 2014) have been exploring methods to evaluate levels of GIS applications in different disciplines and have reported outcomes.

Past studies mainly focused on measuring the usage of GIS in local government and enterprise sectors. The government sector has been one of the dominant areas of measuring usage of GIS techniques because of its long historical use of GIS. O'Flaherty et al. (2005) proposed a model to measure the implementation of GIS and Spatial Data Infrastructure (SDI) within local governments in Thai provinces and classified the usage of GIS and SDI into 4 stages: early implementation stage, growth stage, control stage, and stability stage. Alrwais et al. (2015) developed a method to evaluate usage of GIS based on dimensions of the GIS system, tasks, users, organizations, and GIS department. They tested their measurement tool on Southern California local governments through an online questionnaire. The adoption of GIS in enterprises has attracted notable attention. For instance, Grimshaw (1996) formulated a classification method of measuring GIS applications for selected business organizations using different GIS strategies based on different stages of maturity. Chan and Williamson (2000) developed a three-stage approach to measure the development of GIS adoptions in corporations.

One of the main methods of measuring GIS usage is called the maturity model or stage model that can describe and determine the state of perfection or completeness (maturity) of spatial analysis capabilities. According to Wendler (2012), in measuring GIS usage, a maturity model is commonly applied to measure the potential and complexity of GIS applications. The past studies included various GIS-related measurements such as data availability and accessibility (KEEL, 2008), organizational structure and systems (Alrwais et al., 2015), and GIS Department staff and skills (Giff & Jackson, 2013). The GIS department category presents information about the GIS working environment, including any specific departments for GIS, how many staff in GIS-related departments, and routine tasks for a GIS department (Giff and Jackson, 2013). The GIS applications category displays information related to what functions and software packages are used, as well as what spatial products are utilized and developed by DOTs. The data management category mainly focuses on obtaining information related to how DOTs obtain or collect traffic data, how to manage and process the data, etc. (O'Flaherty et al., 2005). Table 1 presents a summary of studies related to measuring GIS applications.

Table 1. A summary of measuring GIS applications by units and dimensions

Author, Year	Studied Units	Measured Dimensions	Major findings
Grimshaw, 1996	Business organizations (e.g., IKEA, Hinton, Arby's)	Strategy, structure, systems, staff, style, skills, shared values	Classified serval stages of GIS usage, and developed different GIS strategies for each stage of maturity
O'Flaherty, 2005	Local government in Thai provinces	n/a	Presented an extended model to classify the stages of usage of GIS and SDI in local government
Keel, 2008	Enterprises / business organizations	Alignment, data management, accessibility, integration, sustainability	Definitions & characteristics of stages towards enterprise GIS

Giff, 2013	Spatial data infrastructure (SDI) and its stakeholders	Organizational structure, information management, technology, operational processes, customer service	Developed an online self-assessment tool to SDI assessment
Makela, 2012	Both public organizations and private companies, like a state institute, a large private company, etc.	Architectures, service & processes, capabilities	Developed a GIS maturity model for both public organizations and private companies
URISA, 2013	Local government agencies	Technology, data, process, staff, organizational structure	A complete documented model with resources
Kurwakumire, 2014	Public sector organizations in Uganda	Information, availability of data, access to data	Developed an evaluation model for GIS within the public sector based on field data collected in various public sectors organizations in Uganda
Alrwais, et al., 2015	Southern California local governments	Systems, tasks, users, organization, GIS department	Presented a more comprehensive maturity model for evaluating local government usage of GIS along with a measurement tool

Serval studies investigated the GIS usage in a variety of sectors, such as public agencies (Kurwakumire, 2014) and the private sector (Grimshaw, 1996, KEEL, 2008)(Grimshaw, 1996; Keel, 2008). However, few studies have focused on measuring the usage of GIS in the transportation sector, which is one of the main objectives of this study. Based on the review of previous studies and the availability of GIS related data-sharing obtained from departments of transportation at the state level, this study measured and compared levels of GIS applications across 10 different state DOTs in terms of perspectives toward GIS departments, GIS applications, and data management, which are core indicators for measuring the usage of GIS in this study.

2.2 Study Area and Data

This study included ten departments of transportation from the southeastern region of the U.S. (Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee, Virginia, and West Virginia). These studied ten states have a combined population of over 70 million, comprising about 23% of the entire US population (U.S. Census Bureau, 2010). Recently, the DOTs of these ten states are increasingly using GIS techniques in their day-by-day operations, but without DOT-wide standards, the usage of GIS in states' DOTs varies because of different limits of their budgets and resources.

In order to understand levels of GIS applications in Departments of Transportation of the ten studied southeastern states in this study, we collected

GIS usage-related information from the three dimensions of data management, GIS departments, and GIS applications. The core information was obtained from states' DOT websites, collaborating with representatives of the studied states' GIS departments/divisions to verify the information we presented.

3. Comparison of GIS applications in ten state DOTs

3.1 GIS Department

Having a GIS department is a vital indicator to measure usage of GIS techniques because a dedicated GIS department would affect GIS development within an organization significantly (Borges & Sahay, 2000, Olafsson & Skov-Petersen, 2014). Table 2 presents a list of information regarding responsibilities of managing GIS within 10 studied states' departments of transportation.

Table 2. GIS Staff and Skills in state DOTs

State DOTs	GIS program/divisions	Number of Staff	Skill set
Alabama	GIS & engineering support section in computer services technical support division	13	Cartography, GIS dataset, application development and support
Florida	Systems support section in transportation data and analytics office	4	Cartography, GIS dataset
Georgia	IT application support in office of information technology	N/A	Cartography, GIS application development and support
Kentucky	GIS support branch in office of information technology	N/A	Cartography, GIS dataset, GIS application development and support
Mississippi	No specific GIS sector	N/A	N/A
North Carolina	Geographic information systems unit in office of information technology	39	Cartography, GIS dataset, GIS application development and support
South Carolina	No specific GIS sector	N/A	N/A
Tennessee	GIS special mapping section in long range planning division	N/A	Cartography, GIS dataset, GIS application development and support
Virginia	GIS and data warehouse services in information technology division	N/A	Cartography, GIS dataset, GIS application development and support
West Virginia	Geospatial transportation information section in planning and programming divisions	22	Cartography, GIS dataset, GIS application development and support

Above eighty percent of the states' DOTs include a GIS program/division. Those GIS programs/divisions are mainly under the administration of a Planning Department or Information Technology Department, except for the Mississippi DOT and South Carolina DOT. GIS staff numbers vary significantly among states. For example, thirty-nine staff members work in a GIS program in the North

Carolina Department of Transportation, while the Florida Department of Transportation has only 4 staff members in its GIS program. Overall, the main responsibilities of GIS programs/divisions are to provide thematic maps, manage GIS datasets, and develop and maintain GIS applications, while GIS programs/divisions uphold various responsibilities among studied states. For example, the Departments of Transportation in North Carolina and West Virginia operate GIS programs/divisions that actively manage projects and tasks with a relatively large staff.

3.2 GIS Applications

The benefits of operating useful GIS applications in transportation include smart budget, staff, convenience for citizens, and effective communications among stakeholders (governments, non/local residents, businesses, etc.) in terms of planning, development, and risk management in business development and logistics arrangement. Table 3 shows information related to GIS applications in the ten southeastern states' DOTs. Every state DOT adopts real-time traffic web apps and provides real-time traffic information for the public, although the map resources used in web apps are different. Every state DOT presents a set of maps to the public on their official websites, including PDF format maps and interactive maps. Interactive maps are increasingly displayed on each state DOT's official website because those interactive maps make the maps more attractive, and the public can choose how the maps be displayed by selecting functions for the convenience of public users.

Table 3. Map sources and interactive maps: GIS application in each state DOT

State DOTs	Real time traffic		Maps	Interactive Maps
	Map Sources	Application		
Alabama	Google Map	ALGO Traffic	The link node maps by county: The HFC (Highway Functional Classification) The NHS (Enhanced National Highway System) maps by county; ATR Location Map	Alabama Traffic Data; Traffic Counts
Florida	Google Map	Florida 511	County/District Maps; District and Coordinate System Maps; Right of Way Maps; State Highway Map; Turnpike Tolls and Exits Map	Active Construction Projects; Florida Traffic Online; Florida Facility Map; SunPass Program Map
Georgia	Mapbox	511 (Real-Time Traffic Info)	City maps; Intermodal Map; Highway & Transportation Map	State Functional Classification Mapping Tool: GeoPI
Kentucky	Esri	GoKy traffic map	National Highway System (NHS); Right-of-Way Monument Map; Roadway Photo Viewer	Active Highway Plan; Emergency Funding Routes; Bicycle and Pedestrian Facilities
Mississippi	Google Map	MDOT traffic	State / County Highway Maps; Functional Class Maps; Truck Weight Maps	MDOT Traffic Count Application
North Carolina	HERE	Traveler Information Management System	State Transportation Map; Bicycle Maps; County Maps / Bridge Maps / Federal Aid Maps; Highway Performance Monitoring System (HPMS); Traffic Volume Maps	Airport Locations; Blue Star Memorial Marker Locations; Bridge Stats & Structure Maps; Ferry Routes & Terminals; Rest Areas & Welcome Centers; Scenic Byways
South Carolina	Mapbox	511 / Web Camera	State/County/City Maps; Traffic Flow Maps; Functional Class Maps	SC Evacuation Routes; SCDOT Street Finder
Tennessee	Google Map	SmartWay	Functional Classification Maps; Annual Average Daily Traffic Maps; Official State Transportation Map; County and City Maps	Statewide Project Overview Tracker; TNMap General Viewer; Tennessee's State Capitol Monuments
Virginia	Mapbox	Virginia Traffic Information 511	Official State Transportation Map; County / City maps; VDOT Districts Map	Virginia Roads (web application including many interactive maps, like crashes, project, traffic volume, etc.)
West Virginia	Google Map	WV 511 Traveler Information System	WV Urban Area Maps; West Virginia County Maps; County Highway Maps	WVDOT Airport Locations; West Virginia Trail Inventory; WVDOT Park and Ride Locations

Real-time traffic web application is an important interactive tool to provide real-time information to the public, helping people have safer, smarter, and more carefully planned trips while on the road. All ten studied states provide real-time traffic web apps with various information (Table 4), specifically, information on weather, speed, incidents, construction, messages, signs, and special events commonly provided by each state. The Waze information (accidents, traffic jams, hazards, road closings, etc.) is provided by three state DOTs: Tennessee Department of Transportation, Virginia Department of Transportation, and Kentucky Transportation Cabinet. The specific alerts [e.g., rest areas (Mississippi, and Virginia), exit numbers (Virginia), welcome centers (Mississippi), truck parking stations (West Virginia)] are only provided by one or two state DOTs, which should be made consistent to avoid the inconvenience of turning to other maps for the information. Generally speaking, all state DOTs provide similar information to the public like thematic maps, real-time traffic apps, etc., but the information presented in real-time traffic web apps varies.

Table 4. Real-time traffic web applications of 10 states DOTs

		Real-time Traffic application components											
DOTs	Website	Weather	Traffic Speed	Construction	Incidents	Cameras	Special Event	Message Signs	Waze	Rest Areas	Exit Numbers	Truck Parking Stations	Welcome Centers
Alabama[1]	https://algotraffic.com/	✓	✓	✓	✓	✓	✓	✓					
Florida[2]	https://fl511.com	✓	✓	✓	✓	✓	✓	✓					
Georgia[3]	http://www.511ga.org	✓	✓	✓	✓	✓	✓	✓					
Kentucky[4]	http://kytc.maps.arcgis.com/apps/webappviewer/index.html?id=327a38decc8c4e5cb882dc6cd0f9d45d	✓	✓	✓	✓	✓		✓	✓				
Mississippi[5]	https://www.mdottraffic.com/	✓	✓	✓	✓	✓	✓	✓		✓			✓
North Carolina[6]	http://tims.ncdot.gov/tims/	✓		✓	✓		✓						
South Carolina[7]	http://www.511sc.org/	✓	✓	✓	✓	✓	✓	✓					
Tennessee[8]	https://smartway.tn.gov/traffic/	✓	✓	✓	✓	✓	✓	✓	✓				
Virginia[9]	http://www.511virginia.org/	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
West Virginia[10]	http://wv511.org	✓			✓	✓		✓				✓	

✓ denotes the Real-time Traffic application components of each state DOT

[1] ALDOT. (2017). ALGO Traffic. Retrieved from https://algotraffic.com/.
[2] FLDOT. (2017). Florida 511. https://fl511.com.
[3] GDOT. (2017). 511 (Real-Time Traffic Info). Retrieved from http://www.511ga.org.
[4] KYC. (2017). GoKy traffic map. Retrieved from http://transportation.ky.gov/sites/GoKY/Pages/home.aspx.
[5] MDOT. (2017). MDOT traffic. Retrieved from https://www.mdottraffic.com/.
[6] NCDOT. (2017). Traveler Information Management System. Retrieved from http://tims.ncdot.gov/tims/.
[7] SCDOT. (2017). 511 / Web Camera. Retrieved from http://www.511sc.org/.
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[9] VDOT. (2017). Virginia Traffic Information 511. Retrieved from http://www.511virginia.org/.
[10] WVDOT. (2017). WV 511 Traveler Information System. Retrieved from http://wv511.org

3.3 Data Management

3.3.1 Data Collecting

Geospatial data is the core of all GIS applications, and data quantity and quality are of great value in achieving reliable results. Ten studied states' DOTs have multiple ways to collect traffic data (speed, capacity, and flow), sensor data, and crowdsourced data from smartphones. Table 5 lists data sources collected by the ten southeastern states' DOTs. Six data sources are used by states' DOTs; among these, sensor technology is the most used data source, and is collected and used by all state DOTs. Google Maps and INRIX data are commonly used by five states' DOTs, followed by Waze, Mapbox data, and HERE data.

Table 5. Data sources used by each state DOT

State DOTs	Waze	HERE	INRIX	Mapbox	Google Map	Sensors
Alabama			✓		✓	✓
Florida			✓		✓	✓
Georgia				✓		✓
Kentucky	✓					✓
Mississippi					✓	✓
North Carolina		✓	✓			✓
South Carolina			✓	✓		✓
Tennessee	✓	✓			✓	✓
Virginia	✓		✓	✓		✓
West Virginia					✓	✓

✓ denotes the data sources that used by each state DOT

To better investigate the performance of data sources, a comparative analysis was conducted across 10 states' DOTs. Table 6 shows comparisons across six traffic data sources in terms of their functions, data availability, ways to collect data, and data accuracy. The common functions of the apps provide navigation and livemap. The majority of listed apps provide speed data and incident logs. Regarding data collection approaches, three ways of collecting speed data include probe vehicle data, crowdsourced data, and sensor (radar/loops) data. Based on prior research (BATTELLE and SYSTEMATICS, 2007, Hargrove *et al.*, 2016), the most accurate data source is crowdsourced data (Waze, Google Map and Mapbox), followed by probe vehicle data (HERE and INRIX); the least accurate is sensor data.

Table 6. Comparative data sources: Function, Data Availability, Collection, and Accuracy

Data sources	Function	Data availability	Ways to collect data	Data accuracy
Waze	Navigation, livemap, report traffic instance	Speed, incident log	2	★★★
HERE	Navigation, livemap	Speed	1	★★
INRIX	Navigation, livemap, report traffic instance	Speed, incident log	1	★★
Mapbox	Navigation, livemap	Speed	2	★★★
Google Map	Navigation, livemap	Speed	2	★★★
Sensors	N/A	Speed	3	★

Note. Ways to collect data: 1. Probe vehicle; 2. Crowdsourced data; 3. Sensors (radar/loops)

★ denotes the data accuracy level, and more stars means higher accuracy (based on results of BATTELLE and SYSTEMATICS, 2007; Hargrove et al., 2016)

In summary, sensor data has been utilized for decades, but the acquisition of available sensor data is time-consuming, expensive, and complex. Because of developments in technology, crowd-sourcing via smartphone apps and GPS devices is revolutionary in terms of traffic information collection and data analysis. State DOTs show increasing interest in using more crowdsourced data, noting the importance of choosing such data based on their specific needs or goals (Dennis *et al.*, 2015, Transportation, 2018).

3.3.2 Data Display

After data is collected, the analyzed outcomes should be presented in a spatial form, so the public or policymakers can obtain and retrieve relevant information to support their strategic plans and decisions. Table 7 presents the summarized information regarding the GIS-related data displayed. Ten states' DOTs displayed sensor data, maps, and web applications on their web sites, and the public can easily access this data. Eight out of ten states' DOTs presented their GIS data, except for the Mississippi Department of Transportation and Alabama Department of Transportation. Only three state DOTS displayed Waze data outcomes on their websites, which may indicate that public access to GIS data needs to be improved.

Table 7. The GIS-related data displayed by each state DOTs

State DOTs	Sensors data	Waze data	GIS data	Maps	Web Applications
Tennessee	✓	✓	✓	✓	✓
Georgia	✓		✓	✓	✓
South Carolina	✓		✓	✓	✓
North Carolina	✓		✓	✓	✓
Florida	✓		✓	✓	✓
Alabama	✓			✓	✓
Virginia	✓	✓	✓	✓	✓
West Virginia	✓		✓	✓	✓
Mississippi	✓	✓		✓	✓
Kentucky	✓	✓	✓	✓	✓

✓ denotes the data displayed by each state DOT

4. Conclusion and Future Work

Logistic travel routs and effective transportation systems are vital for tourism industries. As mentioned earlier, despite the wide adoption of Geographical Information System (GIS) techniques to analyze issues in the travel and transportation sector, few studies have been done to investigate levels of GIS applications at state levels. GIS is an advanced technology that demonstrates logistics and offers spatial mapping functions to support decision priorities and strategic goals for public, private, and voluntary organizations and users at all levels. States' DOTs have recognized the merits of GIS techniques and the importance of further GIS implementation to support their transportation analyses. We found that reviewed studies mainly focused on local governments and enterprise sectors, while a few of them studied GIS usage in the transportation sector. Our goal was to investigate the levels of GIS implementations in states' departments of transportation to fill this gap. Through summarizing common indicators that were used to measure GIS usage, we selected our case studies to examine how GIS-related programs have been adopted in the past decade. The nature of our study is descriptive and qualitative. We provided an analytical framework to compare the adoption of GIS across states' DOTs. Indicators chosen were based on previous studies' recommendations and current practices among states' DOTs.

Given a lack of knowledge of levels of applications of GIS, the potential benefits from GIS cannot be fully obtained. The objective of this study is to gain an understanding of and compare the adoption of GIS across states' DOTs. In this study, we investigated levels of applications of GIS in DOTs of the Southeastern Region of the U.S (including Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee, Virginia, and West Virginia) based on their spatial data availability and the depth of GIS adoptions across ten states' DOTs. Comparisons among these ten states DOTs have been made to obtain in-depth understanding of the applications of GIS in states DOTs.

Real-time traffic web application is an interactive tool that provides real-time information for the public that aims to help people have safer, smarter, and better planned trips. In this study, the core information was obtained from states' DOT websites because those state DOTs serve as an important window to convey information to the public. The results showed that eight out of ten state DOTs have a dedicated GIS department or division to manage states' DOTs GIS tasks and projects. Additionally, all of the studied ten states' DOTs have developed serval GIS applications to provide useful traffic-related information for the public, such as real-time traffic web applications. Among the studied ten states, data sets, thematic maps, and real-time traffic information listed within the real-time traffic web applications are all similar. The main data sources collected and used by state DOTs are multiple, including WAZE, GOOGLE MAP, HERE, and INRIX, while every state DOT used only one or two data sources due to budget constraints. In general, each state DOT provided fundamental spatial information or data to the public, but further advanced information will be needed for the sake of public safety and convenience.

It is noted that this study provides a first step in measuring GIS applications in the transportation sector, specifically state DOTs, and also provides a foundation that can be built upon by others. In addition, the results of this study should be useful to local authorities and can be used to help officers understand GIS usage and learn from other cases. For example, to improve the application of GIS, improvements can be made such as staff GIS skills training and public GIS knowledge and adoptions.

A few limitations exist. First, this study only presented a descriptive investigation of various applications of GIS techniques per GIS adoptions by the studied ten southeastern states' DOTs. Further quantitative analyses and users' evaluations may be considered by utilizing models and surveys in order to quantify data accuracy and usage efficiency at a national level. Second, comparisons among ten state DOTs are rough and general without using any quantitative or qualitative indices. Therefore, future studies may consider developing a list of general and core indices, such as the efficiency of timely communications between governments and on-the-road users. Third, the efficiency of GIS usage and benefits gained from implementing GIS need to be quantified and further investigated. For example, future studies may consider exploring the relationship between GIS usage and GIS benefits across the whole nation. Examining the exact benefits from the usages of GIS techniques and evaluating whether the usages of GIS techniques are translated to actual benefits for the communities, residents, and travelers can assist policymakers at local and state levels to formulate suitable strategies in order to optimize their future development planning.

Acknowledgments: We appreciate the journal reviewers' feedback.

Author Contributions: Zhihua Zhang drafted literature reviews and descriptive analyses. Dr. Rachel J.C. Chen guided the project with direction and ideas, added value to methods and recommendations, rewrote and edited the manuscript. Dr. Lee D. Han prepared the graphic abstract, guided the project with ideas and added value to recommendations.

Conflicts of Interest: The authors declare no conflict of interest.

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