The Application of Geographic Information System (GIS) on Five Basic Indicators of Sustainable Urban Transport Performance

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Abstract. As the era of information technology today, the use of digital information is very useful in the process of data collection, analysis and modeling. A Geographical Information Systems (GIS) is not only a tool, but it is also has a powerful ability in the analysis process, included to measure the performance of transportation in sustainability issues. The purpose of this study is to show how GIS can be used to analyze Sustainable Urban Transport performance based on its basic indicators. This paper used literature review in the field of GIS approach in sustainable urban transport studies with using classification methods from the sources with certain procedure. The paper shows the GIS application in urban transport performance studies on five basic indicators: traffic congestion, traffic air pollution, traffic noise pollution, traffic accident and transport infrastructure. The study found that the use of GIS in urban transport performance studies is dominant on traffic congestion indicator and the tool of GIS which used to measure transport performance mainly by the shortest path. It is interesting how to measure the performance of Sustainable Urban Transport (SUT) to be more comprehensive with involves all basic indicators i.e. traffic congestion, traffic air pollution, traffic noise pollution, traffic accident and transport infrastructure.

Keywords: GIS · Sustainable urban transport · Basic indicator Performance

1 Introduction

As a system with a computer-based methodology for collecting, managing, analyzing, modeling, and presenting geographic or spatial data, GIS has a powerful ability to analyze a variety of planning problems [1]. This capability makes it easy for planners to determine decisions more effectively and efficiently. The problem of transportation that continues to grow requires an effective remedy. The role of GIS as an analysis tool gives a big influence in providing solutions to solve the problems of transportation. The advantages of GIS in data integration and map display provides comprehensive analysis and information with very accurate and convincing results. GIS has functions that support the transportation system through statistics analysis, charting, decision support systems, modeling and databases, also encoding, management, analysis and reporting [2].

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The natural environment is a human dwelling to live in the world that was inherited and will continue to be inherited in the future. The existence of a comfortable habitat necessary to establish events life for the residents. These events are characterized by movement in the form of transport as the backbone of community activities. Transportation plays a vital role in keeping human activity vibrant, therefore careful attention must be given to it in order to support sustainability. There is a trend that growth is ever so rapid in all countries now and more so in the future to come. Therefore, the attention in sustainability development becomes important. The increase of urban population is directly proportional to the increase in needs of the movement in urban transportation. The performance of urban transport should be measured in an effort to prepare future community. There are several analytical techniques to assess relationship between land use and transport i.e. descriptive statistics, spatial mapping, spatial statistics, travel preference functions, regression analysis, selection of suitable predictive models based on-time series census data and application of travel models scenarios for land use distribution [3]. As for this study, the GIS will be explored as tool to analyze the performance of urban transport to be sustainable.

Trends and issues in sustainability and urban transport has become more popular in rapidly growth city, especially developing countries which have bigger population with middle-income and where the rate of ownership of private vehicle is significantly high. The purpose of this paper is to review the GIS application to measure sustainable urban transport performance based on its basic indicators. To achieve this purpose which in other words is the research objective, let us start with by way of determining the research question: what are the trends of use of GIS for analyzing urban transport performance and sustainability in current practices? The structure of this paper consists of several parts: first, to find all papers related to the study of Sustainable Urban Transport using the GIS approach; second, to perform specifications to measure the performance of Sustainable Urban Transport based on five basic indicators; third, to classify into five main categories; finally, the results and findings.

2 Materials and Methods

The sustainability of transportation needs to be improved. The scope of the regional and local objectives in sustainable transportation consists of five indicators i.e. air pollution, noise pollution, congestions, accidents and land consumption [3]. Similarly, basic concern must be focused in environment, economy and society i.e.: traffic congestion, emission/air pollution, noise pollution, non-renewable resource consumption, and road safety/traffic accidents [4]. Also, the common issues of transportation (specifically in Asia Region) need more to be explored is about traffic congestion, traffic accidents and air pollution [5]. Land consumption by transport infrastructure and noise pollution as interesting issues for the future problems. Based on previous research, this paper focuses in five basic indicators of sustainable transportation i.e. traffic congestion, traffic air pollution, traffic accident, transport infrastructure and traffic noise pollution. The GIS analysis also arranged to focus in these issues.

This paper based on a review of international journal studies, thesis, textbooks, and conference proceeding papers. The journals were selected through electronic search

topics on the field. During the electronic search, the authors used key words or terms: GIS and urban transport, sustainable urban transport, and sustainable urban transport performance. The first term is utilized to generate all papers that treat the relationship topic between GIS approach and Urban Transport sector, including papers referring to this subject in different methods and techniques used. The second term aims to find all papers related to Sustainable Urban Transport studies, this attempt was to delimit papers that were related in the transportation sector. Finally, the last terms are adopted to generate more specific search result about how to measure the performance of Sustainable Urban Transport based on the five basic indicators.

The electronic sources that the authors used were from Science Direct, Springer Link, and Scholar Google. Also the authors examined some references cited in each relevant literature source to obtain additional sources of knowledge. The research covers a period of more than ten years between 2000 and 2016. Next step, the authors excluded all papers that were not related to the GIS approach and Urban Transport sector, through identification on the title of journals, abstract and introduction section. As a result, the papers with only specific in GIS approach and urban transport performance based on the five basic indicators were analyzed in this study. In this study, the authors used literature review and research of GIS in the field sustainable urban transport. In contrast to previous studies that had discussed GIS and the transport sustainability in general, this study will focus on 5 basic indicators of sustainable urban transport (SUT) only. The studies will be classified into five major categories: (i) publications with year and number of articles, (ii) scientific institutions-country case studies, (iii) types of studies, (iv) types of GIS application in analyzing of five basic indicators of SUT, and (v) types of GIS tools in measuring of five basic indicators of SUT.

3 Results and Discussion

The result of the search extrapolated studies related to utilizing of GIS tools for measure urban transport performances especially in 5 indicators i.e. traffic congestion, traffic air pollution, traffic noise pollution, transport infrastructure, and traffic accident. Based on years of publication from 2000, generally the research that discussed the SUT had a tendency to in-crease until 2016. Based on Fig. 1 shows that the interest of researchers is high and increasingly related to GIS analysis for measure urban transport performance. Results of exploration in the search engine revealed 33 studies that specifically deals with GIS analysis in Urban Transport. Based on the search results it shows that at the beginning of the year's trend up to 2004, but in the year between 2005 and 2006 it experienced a drastic decline and then again showed a trend of trend to increase beginning in 2007 until 2016.

The area of study represents countries in all the continents of the world from Africa, Asia, Australia, America and Europe. Some studies showed a significant result by 5 studies in UK, 4 studies in Saudi Arabia and 3 studies in USA. The overall picture of the distribution of case studies on the theme of GIS analysis in Urban Transport can be seen in Fig. 2.

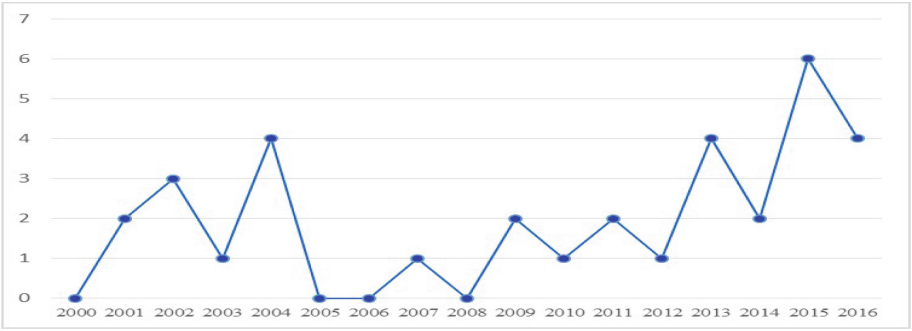

Fig. 1. Papers by year of publication of urban transportation in 5 basic indicators performance using GIS

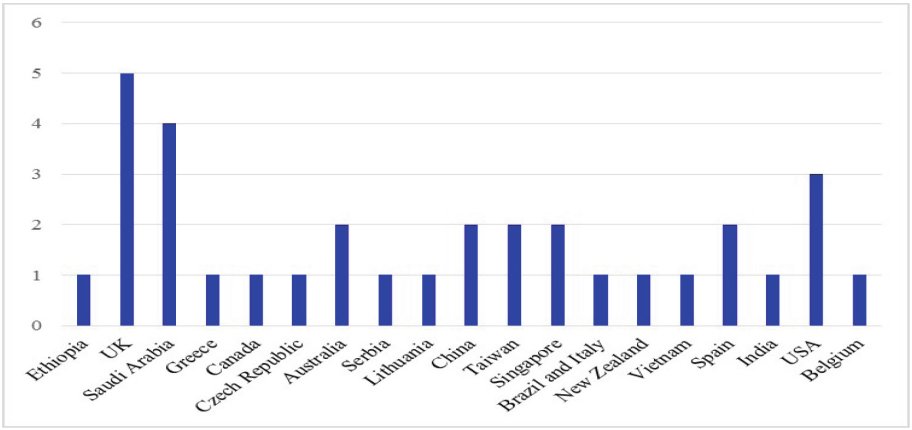

Fig. 2. Country of publishers on urban transportation studies in 5 basic indicators using GIS over period 2000–2016

The previous studies relating concern between GIS analysis and Urban Transport journals searches with the time period 2000 to 2016 shows in this paper. The results indicate that Scholar Google provides the highest results of 20 studies, followed by Science Direct were 9 studies, 10 studies by Elsevier and other Springer Link as a study, as shown by Fig. 3. It shows how far the ability of each researcher to contribute in improving the dissemination of knowledge, especially through the media publisher, and the level of success of the study search engine in providing services to researchers in the quest the desired study.

The results of searching process also shows the discovery of several types of studies related to the SUT. Studies in the type of a paper as the highest by 29 studies. Furthermore, the form of proceeding by 2 studies, theses and book section respectively of a study. It can be seen in Fig. 4.

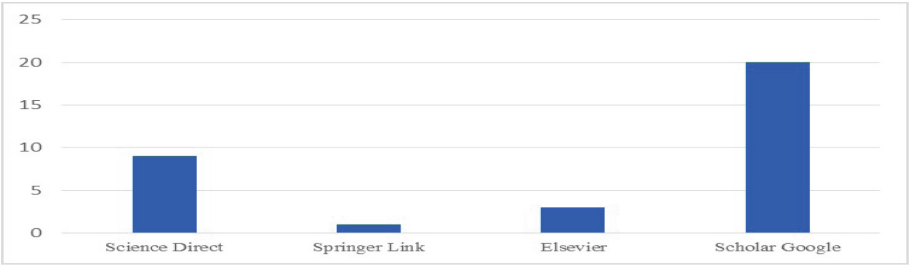

Fig. 3. Results of study search engine in urban transport performance studies using GIS topic

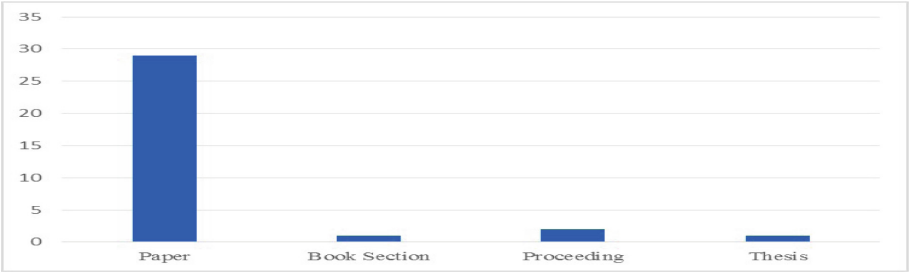

Fig. 4. Type of study in urban transport through five basic indicators using GIS

On the criteria of journal titles, found some journals as choice of the researchers to publish their research. On the many titles in studies found five titles journal is a journal title chosen most researchers in the topic of the SUT i.e. Accident Analysis and Prevention, Applied Acoustics, International Journal of Geo-Information, Journal of Transport Geography and Journal of Geographic Information System (Table 1).

The findings of previous studies generally illustrate the use of GIS analysis to measure the performance level of urban transport. Increasing the researcher's attention to transport performance from various disciplines and point of view through the use of

Table 1. Journal titles, total citations and average annual number of citations

Journals title	Paper numbers	Total citations*	Ave. cit. per year*	H index*
Accident Analysis and Prevention	2	2879	2.25	94
Applied Acoustics	2	933	1.85	49
International Journal of Geo-Information	2	931	2.57	79
Journal of Transport Geography	2	1333	2.49	58
Journal of Geographic Information System	2	1502**	No data	15**

*Source: www.scimagojr.com, **Source: http://www.scirp.org

GIS as an analytical tool spawns a range of findings and concepts in support of sustainable urban transport. Various types of GIS analysis are presented by previous researchers in measuring urban transport performance by optimizing various tools with diverse functions. There are more in-depth findings regarding the use of GIS in urban transport studies as presented in the following section.

3.1 The Types of GIS Application in Analyzing of Basic Indictors of SUT

In category of GIS application and objectives, papers is classified as main topic of GIS application in urban transport research. As the urban transport knowledge very large, especially how to measure its performance, the authors filtered of the papers in main objects of the studies and what is depend on. Each papers also consist of several objective to describe the urban transport performance. The GIS application types used in the previous studies in five basic indicators of the Sustainable Urban Transport summarize in Table 2.

Table 2. GIS application in analyzing of 5 basic indictors in sustainable urban transport (SUT)

Indicators	Objectives	Authors
Traffic congestion	- Investigation of network shortages that are an obstacle to accessibility	[6]
	- Development of social needs index of composite public transport	[7]
	- Identification of lacking facilities in vital areas within the capital's ring road	[8]
	- The development of simple GIS-based methods to analyze rapid accessibility with different modes of transport	[9]
	- Analyze accessibility and other indicators to show troubled transport zones	[10]
	- Integrated GIS development on accessibility analysis	[11, 12]
	- The depiction of two public transport access measurements: a combination of public transit and access indexes and transit frequency sizes	[13]
	- Evaluation on the contribution of 'major' land use in the region to traffic congestion in certain corridors and to test how relocation can reduce traffic congestion	[14]
	- Measurement of congestion using fuzzy logic and create strategies to reduce congestion	[15]
	- Modelling dynamic congestion spread effects	[16]
	- Evaluation of traffic congestion during working hours in accordance with road direction	[17]

(*continued*)

Table 2. (*continued*)

Indicators	Objectives	Authors
Traffic air pollution	- Improved efficiency of transport supply in improving the environment	[18]
	- Analyze the emission implications to reduce motor vehicle emissions in urban transport	[19]
	- The depiction of air pollution consequences to the environment as a result of road transport	[20]
	- Present a preliminary study to evaluate the air pollution situation related to urban transport	[21]
	- Modeling temporal and spatial variability of traffic air pollution	[22]
	- Characterization of intra-urban distributions NO_x and NO_2, and land-use regression (LUR) to assess NO_x and NO_2 outdoor concentrations	[23]
Traffic noise pollution	- The depiction of GIS-based modeling systems in assessing the environmental impact of road traffic plans	[24]
	- Development of road traffic noise maps day and night	[25]
	- Modeling to assess TRAffic Noise EXposure (TRANEX)	[26]
	- Testing of the adequacy of data to generate urban noise maps and verifying the application of environmental noise mapping disturbance models	[27]
Transport infrastructure	- Assessment of territorial effects from new linear transport infrastructure	[28]
	- Identification with sustainability metrics on environmental, economic, and social factors of the transport project	[29]
	- Development of appropriate methodologies that explicitly link transportation infrastructure with the impact of strategic sustainability	[30]
Traffic accident	- An investigation of the use of GIS tools in assessing traffic accidents/transport system safety performance integrating spatial parameters and indicators	[2]
	- Use of a methodology using GIS and Kernel Density Estimates to study the spatial patterns of road accidents related to injury	[31]
	- The clustering methodology uses environmental data and results from the first section to create a road accident hotspot classification	[31]
	- Establish procedures to evaluate traffic accident groups and arrange them according to their significance	[32]
	- Depiction of trends in Road Traffic Accident (RTA) and to raise consciousness of RTA issues in developing countries	[33]
	- Determination of the location of the area marked by the concentration of traffic accidents (black zone) involving Vulnerable Road Use (VRU)	[34]
	- Identify traffic accidents through integration between NetKDE and local Moran'I for hot spot detection	[35]

The research objective in SUT performance using GIS is dominantly by traffic congestion indicators with 12 studies, secondly by traffic accident indicators with 8 studies, thirdly about traffic air pollution with 6 studies, following by traffic noise pollution with 4 studies and transport infrastructure with 3 studies. Figure 5 shows the papers number used GIS approach in five basic indicators of transport performance studies.

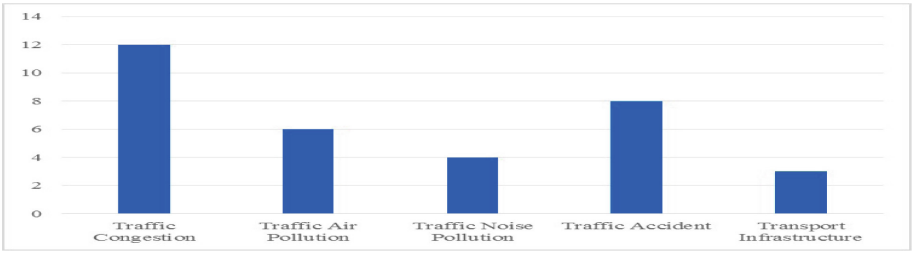

Fig. 5. Number of studies in 5 basic indicators of SUT using GIS

Figure 6 describe a number of studies with its research methods. Found about 8 types of methods used by previous researchers on the GIS for SUT theme. Modelling method widely used as many as 24 studies. Then followed by decision support system and literature review methods as much as 2 studies.

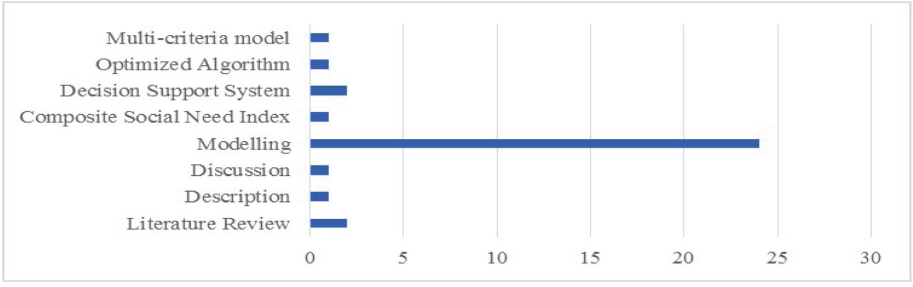

Fig. 6. Types of research methods in urban transport performance using GIS

From the survey between 2000 and 2016 above, we find the fact that the methods used by the researchers in sustainable urban transport (SUT) studies using GIS are mostly using one indicators of SUT, still rare using more than one indicators. Of course this is an interesting finding that needs to be studied more comprehensively by involving more than one indicators or all of the five indicators as a basic indicators. Modelling methods dominantly used by earlier researchers as convincing methods to be use in future research.

3.2 The Types of GIS Tools in Measuring of Five Basic Indicators of SUT

Previous researchers used a variety of tools from GIS analysis to measure the performance level of indicators on urban transport each researcher has a way of exploring the information and analyzing it by involving certain scenarios resulting in reliable research. The papers is classified based on GIS tools was used in research to analyse urban transport performance. The GIS has many type of tools as instrument to be used in analysis process of the research. The function of GIS tools in each research according focus of the object research. Each function have unique function depend on creativity of the researchers to measure performances of urban transport. Based on the results of a review in previous research, the following describes several types of GIS tools and their functions summarize in Table 3.

Table 3. The classification GIS use by tools in transport performance studies

Indicators	GIS tools	Function	Authors
Transport congestion	Buffer analysis	- To measure the range of the route/stop - To represent the impact area	[6] [8]
	Quantities analysis	- To measure routes number per segment of road	[6, 7]
	Shortest path analysis	- To produce the shortest route between proposed interactive project points - To estimate the volume of traffic contributed by these primary land uses in the corridor during peak hours	[8, 11, 12, 14, 15, 17]
	Deficiency analysis	- To identify the lack of facilities, the relationship between link capacity and estimated volume	[8]
	Allocation of resources	- To identify the distance and travel period of various points of interest on the street GIS network map	[8]
	Simple additive weighting/SAW	- To measure with the greatest value which means the best transport situation in a particular traffic analysis zone	[10]
	Network analyst	- To create a multi-modal network that combines transit mode and runs using travel time as network impedance	[13, 15, 17]
	What If questions	- To create strategic planning and tactical management of unplanned network disruptions	[16]
	Overlay analysis	- To determine the congestion point according to the direction of the road	[17]

(*continued*)

Table 3. (*continued*)

Indicators	GIS tools	Function	Authors
Traffic air pollution	Geo-database	- To generate thematic diagrams, tables and maps	[18]
	Geocoding	- To input the field data to the GIS attribute	[19]
	Network analyst	- To test transport policies in terms of emission effects at the link level and merged to the regional level	[19]
	KDE	- To present the center of air pollution in area	[19]
	Dispersion model (grid cells)	- To integrate the outputs of transport planning activities with land use information based on user-defined grid sizes	[21, 24]
	Transport Add-on Env. Model. Syst./TRAEMS	- To integrate traffic information from the travel forecasting model for input data used in various models in estimating pollution	[20]
	Buffer	- To calculate the path length of the total traffic variable of the day and the distance to the nearest road	[22]
	Geostatistical analyst	- To present the spatial distribution of NOx and NO2 in urban areas drawn by ordinary kriging method	[23]
Traffic noise pollution	Dispersion model (grid cells)	- To model the noise impact of different road traffic scenarios	[24]
	What If question	- To model noise calculations, environmental noise presentations, noise reduction design	[36]
	PostGIS	- To handle large vector data sets to be more effective	[26]
	Geocoding	- To produce a measurable acoustic parameter noise map	[27]
Transportation infrastructure	Spatial analyst	- To create sustainability metrics for the selection of transit infrastructure projects	[29]
	Spatial classification	- Modeling as a graph with a set of vertices and an arc	[30]
	The TITIM	- Evaluation of accessibility improvement, landscape connectivity, and impact on other local area variables	[28]

(*continued*)

Table 3. (*continued*)

Indicators	GIS tools	Function	Authors
Traffic accidents	Network analyst	- To measure the level of traffic accidents - To present transport performances - To measure safety level caused by traffic accidents	[2] [37]
	Kernel density estimation (KDE)	- To know the spread of accident risk - To identify dangerous locations on the road - To calculate the probability density function of each crash site	[31, 33] [32, 35] [34]
	K-means clustering	- To create a road accident hotspot classification	[31–33]

The use of GIS tools in reviewed papers is dominant by the shortest path analysis, kernel density estimation (KDE) and network analyst as shows in Fig. 7. Urban Transport Performance is how well urban transport to serve the society activities as navigation tools to achieve the goals. An essential topic for sustainable development is to encourage efficient urban transportation systems while decreasing their negative impacts [38]. A sustainable transportation system is one that: tolerates the elementary access needs of individuals and societies, to be met safely and in a manner consistent with human and ecosystem health, and with equity within and between generations; operates efficiently, offers choice of transport mode, and supports a vibrant economy; and limits emissions and waste within the planet's ability to absorb them, minimizes consumption of non-renewable resources, limits consumption of renewable resources to the sustainable yield level, reuses and recycles its components, reduces the use of land and minimizes the production of noise [39]. According the literature, there is a need for comprehensive analysis using basic indicators of sustainable urban transport

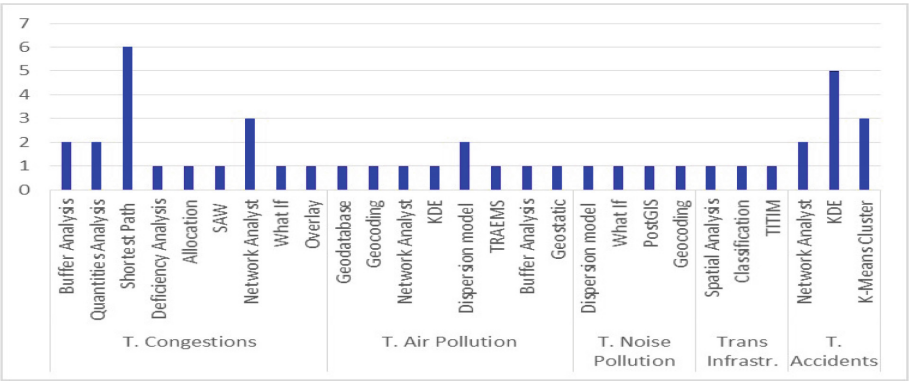

Fig. 7. The use of GIS tools to measure sustainable urban transport studies

performance as instruments to measure performance of sustainability includes economy factors, environment factors and social factors.

GIS is considered as a useful tool for transport planners in defining how well the movement of people or goods from one place to another place, also measure, predict, evaluate and monitor the degree to which the transportation system accomplishes adopted public objectives [40]. The interesting function of indicators are used for a variety of purposes including measurement, policy formulation, and project assessment [41]. Performance measures are measurable criteria that are utilized to evaluate progress towards goals [42]. According [43] also suggest that indicators should be used to measure progress, inputs, and outputs of a transport project. Furthermore, [44] that selecting the indicators can greatly influence the analysis results. Therefore, the steps of selecting indicators must be with carefully actions. As this study results that the use of GIS in SUT performance studies dominantly by traffic congestion, traffic accidents and traffic air pollution. For methods type of the research, in previous research mostly by modelling methods. Then GIS tools which used to measure SUT performance indicate that dominantly by shortest path, Kernel Density Estimation (KDE) and Network Analysis.

According the result of this study result, in measuring sustainable urban transportation performance, dominantly with traffic congestion indicator using shortest path analysis. Indicator of traffic air pollution generally using dispersion model (grid cells) to measure the performances. For traffic noise pollution, the previous study also used dispersion model (grid cells) and other tools such as What If?, PostGIS, and Geocoding. In measuring transport infrastructure three GIS tools used i.e. spatial analysis, classification and TITIM. Also in analyzing traffic accidents using three GIS tools i.e. network analyst, KDE and K-Means Cluster. Based on observations in previous research, it was found that in general the research topic only discusses one or two aspects of the basic indicator of sustainable urban transport. Whereas the performance of sustainable urban transport based on the scope of the study needs to be comprehensive or at least can meet the basic indicators. Therefore this is an interesting gap knowledge to be explored more deeply based on five basic indicators using GIS approach, such as congestion, traffic air pollution, traffic noise pollution, land consumption for transport infrastructure and traffic accidents.

4 Conclusions

This paper objectives to review of the literature on the use of Geographic Information System (GIS) in analysing sustainable urban transport performance studies. The paper introduce an approach based on classification scheme technique where research journals in this field are collected, classified and results are interpreted. A comprehensive literature study done through a classification model adoption. The study has explored the GIS application in urban transport performance studies focus on five basic indicators: traffic congestion, traffic air pollution, traffic noise pollution, traffic accident and transport infrastructure. The classification could represent countries on all continents in the world, from Asia, Australia, Africa, Europe and America within period 2000 until 2016 and found that UK country as dominantly in this case. Scholar Google provides

the highest productive search engine and also found that paper type as majority in SUT studies. In category of journal name, Accident Analysis and Prevention, Applied Acoustics, International Journal of Geo-Information, Journal of Transport Geography and Journal of Geographic Information System as the most chosen by the previous researchers. For category of studies numbers in five basic indicators of SUT, traffic congestion as mostly concern by previous research, following with traffic accident, traffic air pollution, traffic noise pollution, and transport infrastructure. In the category of research method, modelling as dominant in previous research, and for category of GIS tools, mostly researcher used i.e. Shortest Path, Network Analyst, KDE and K-Means Cluster. The use of GIS in previous research still focus in one or several indicators in measuring performance Sustainable Urban Transport. According to the literature, there is interesting for future research to know GIS application with comprehensive analysis using all of the five basic indicators i.e. traffic congestion, traffic air pollution, traffic noise pollution, traffic accident and transport infrastructure as instruments to measure sustainable urban transport performance.

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