

# Reviewing the use of Geographic Information System (GIS) to measure Sustainable Urban Transport performance

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## Abstract

The purpose of this paper is to show how Geographical Information Systems (GIS) used to measure the performance of Urban Transport Sustainability. The first, this paper discusses about understanding about transport performance and how to measure it. The second, explore about sustainability in urban transport. The third, defines GIS and its possible uses in the sustainable urban transport performance. The relevant GIS functions have also been explained. The GIS models are explored to assist urban transport planner to measure sustainability in urban transport.

**Keywords:** Sustainable Urban Transport, GIS, performance

## 1. Introduction

The natural environment is a human dwelling to live in the world as inherit the past and will be inherited to the future. The existence of a comfortable habitat necessary to establish events life for the residents. Their events characterized by movement in the form of transport as the backbone of community activities. Transport as vital role in making human activities, so need attention in supporting the sustainability. Trends in rapidly growth of urban population in all countries in the near future. 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 effort to prepare future community. Several analytical techniques to assess relationship between land use (urban form) and transport i.e. descriptive statistics (exploratory and graphical methods), 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 (Black et al., 2002). While, this study will be explore the use of Geographical Information System (GIS) as a tool to analyze the performance of urban transport to be sustainable.

Trends issues in sustainability and urban transport become most popular in rapidly growth city, especially developing countries which have

bigger population in middle-income and vehicles ownership is more in rates. The purpose of this paper to review the use of GIS for measuring sustainable urban transport performance. To achieve purpose of the research objective, start with improve the research questions; what are the trends of use of GIS for measuring urban transport performance and sustainability in current practices? The issue of sustainable development is affecting a paradigm in urban transport in recent time. The urban transport performance is driven towards development reflects sustainability efforts. Therefore, this objective study is to describe the use of GIS in measuring sustainable urban transport performance studies.

## 2. Methodology

### 2.1 Literature search procedure

Survey based on international journal studies, include doctoral dissertation, master thesis, books, unpublished working papers and conference proceeding papers. The journals select through electronic search topics on the field. During searched in electronic search, the authors used some 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 sustainable urban transport studies, this attempt to delimit papers that related

in transportation sector. Finally, the last term are adopted to generate more specific search result about how to measure the performance of Sustainable Urban Transport.

The electronics sources that authors used through explore Science Direct, Springer Link, JSTOR, and Scholar Google. Also the authors examine some references cited in each relevant literature source to obtain additional sources of knowledge. The research covers a period of more than twenty years between 1996 and 2016. Next step, authors exclude all papers that are not related to the GIS approach and Urban Transport sector, through identification on the title of journals, abstract and introduction section. As the result, the papers with only specific in GIS approach and urban transport performance analysed in this study.

## 2.2 Classification methods

In this stage, the authors used literature review and research in the field GIS approach and Sustainable Urban Transport. The paper is classified into two major categories: (i) GIS application and objectives in Transport Performance and (ii) GIS tools and functions for analysis of transport performances.

### a. GIS application and objectives in urban transport performance

The 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.

### b. GIS tools and functions for of urban transport performance

According this criterion, 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.

## 3. Results and Discussion

In GIS has several spatial analysis tools that can be applied to measure performance of sustainable urban transport. These applications vary from accessibility, air pollution (emission), noise pollution, energy consumption, public transport, transportation network, traffic, and transportation infrastructure. One of the important issue is to define the sustainability of transport performance in urban area. GIS as tools can great to assist for researcher to measure the level of sustainability in urban transport performance. There are many of GIS analysis in transport performance studies in previous research.

## 3.1 Classification by GIS application and objectives to measure transport performances

### a. Accessibility

One main topic to present the transport performance is about accessibility. This topic described through (Paudel et al., 2009) which used ArcMap-GIS software in his research to identify dairy manure transportation routes that minimized costs relative to environmental and other constraints with using tools analysis: network analysis. Similarly, a study by (Gutiérrez et al., 2010) used ArcGIS with network analysis tools in order to calculate and map regional spillovers, economic potential values are computed using network routines. Furthermore, (Mavoa et al., 2012) used GIS through network analysis to measure of accessibility aggregate and accessibility measures. Network analysis also used to define the health care locations in order to determine the levels of accessibility (Murad, 2005), as versatile tool to integrate land use and transport system components in an accessibility metric (Ford et al., 2015), to measure the accessibility to transit network for households and cars (Chapleau and Morency, 2005), to know how far patients live from their nearest health centers (Murad, 2004). Buffer analysis also to measure distance from each dairy farm to receiving farmlands (Paudel et al., 2009), to measure geography framework (O'Sullivan et al., 2000), to define the retail center catchment (Murad, 2003), to evaluate the accessibility to health care facilities (A. A. Murad, 2014) and the dynamic measure of relative accessibility of households to the nearest bus stops (Chapleau and Morency, 2005). For overlay analysis used to having a GIS layer with patient data and facilities catchment area (Murad, 2004), to find out health centers with a large number of physicians but without any dentists or with fewer servants (Murad, 2011), designated as **“intersect” for the new catchment areas and for the city districts’ coverage. Commonly in measuring accessibility, previous researchers used network analysis, but several studies used buffer analysis and overlay analysis. The use of GIS tools in reviewed paper found tools in single form such as just network analysis or mix with buffer analysis, overlay analysis and classifications analysis.**

### b. Air Pollution (emission)

Measuring of air pollution as effect traffic network in the whole area serviced to estimate the various pollutant level (Brown and Affum, 2002) become as a part of sustainable urban transport. This study used network analysis in GIS to estimate the main pollutants from road network and environmental consequences. Likewise, (Paudel et al., 2009) used networks analysis to identify transportation routes that minimized costs relative to environmental constrain. GIS also used to applied in geo-code trip origins and destinations to calculate the emission in transportation activity (Armstrong and Khan, 2004). GIS also used to develop the spatial information, urban road

network and distribution of pollutants in the atmosphere (Lin and Lin, 2002). Dynamic simulation models in GIS was developed to describe traffic flows, the emission from traffic and resulting air quality (Fedra, 1999);(Gualtieri and Tartaglia, 1998). With quintile analysis and thematic maps, GIS used to model air pollution and GHG emission from vehicles through Transport Add-on Environmental Modelling System (TRAEMS) (Gharineiat and Khalfan, 2011). Similarly, (Alshuwaikhat and Aina, 2006) points to GIS with network analysis and buffer analysis to assessment an unacceptable level of air pollutant by citizens. Emission modeling and evaluation of environmental impacts have analysed using network analysis in GIS to estimate and reproduce traffic behavior and calculate pollutant emissions. Based on these previous research as commonly the researchers measure air pollution or emission as effect of urban transport activity used network analysis and buffer analysis in GIS environment. It used to describe the influence of pollutant **throughout the roads and it's around, also to assess** of environmental consequences.

c. Noise pollution

Heavy traffic road resulting the noise pollutant as challenge for urban transport planners to manage and solve the problems. (Li et al., 2002) used FHWA model as integrated system to calculate noise in traffic road then translates it into a syntax that ArcViewGIS understand in spatial and non-spatial data. Whereas, (Brown and Affum, 2002) used TRAEMS model to measure noise pollution with three main methods: embedding in GIS tools, implementing the models in GIS and interface approach. Using SIAM methods, (Antunes and Santos, 2001) assess noise impacts of traffic network in GIS environment to generate, storage, data management, overlay, classification, aggregation analysis, trend analysis and display of the thematic information. Noise pollutant become trends topic in a part of sustainable transportation as rapidly growth of private vehicle ownership in urban citizen. Road load not just affected in construction and air pollution, but also in the increasingly of noise as vehicle machine effect. The previous researchers used statistics calculations and GIS approach to describe the phenomena thoroughly network analysis, buffer analysis, and classification analysis.

d. Energy consumption

Energy consumption in traffic assignment, explored by (Arampatzis et al., 2004) with GIS utilization for policy definition, traffic simulation and analysis, energy consumption and pollutant emission modelling, and evaluation of environmental impacts and its scenarios. GIS tools was implemented according to a three-stage: the database, mathematical models for traffic assignment, the presentation in thematic maps, figures and diagrams. Similarly, (Gharineiat and

Khalfan, 2011) used GIS as tools to make energy efficiency planning in traffic vehicles. Issues efficiency of the use of energy as interesting point in sustainability studies. Energy sources become limited, whereas the energy use more excessively. Previous researchers used GIS to analysis and present energy consumption in traffic road network, calculate the effect with spatial indicators approach.

e. Public Transport

One issue about sustainable urban transport is to encourage the **use of public transport in society's** daily life. GIS approach also used by transport planners to measure the performance of public transport in studies area to know level of services, accessibility and catchment area from the stations. According (Miller and Storm, 1996) that GIS design have several key features as advantages in public transport studies, such as: accurate illustration of the multi-modal transport network, flexible in updating database, user friendly in interfaces and proficient in implementations. His research used network equilibrium-based travel demand as methods and network analysis in GIS application. Isochrones methods used by (O'Sullivan et al., 2000) in measuring public transport performance with two approaches, such as accessibility measures and the space-time geography framework through GIS tools with network analysis and buffer analysis. Catchment area methods (Abosuliman et al., 2011) and classification methods (Aljoufie, 2016a) are used GIS with analysis network to present public transport network. Similarly, (Abreha, 2007) used network analysis to assess the level of service of the existing public transport system and to identify deficient network elements. Also, used buffer analysis to buffer distance from bus route and overlay analysis in network and land-use with classification method. GIS applications have some advantages to analyse the public transport studies accordingly with good illustration in transport network, flexibility for updating data, and simple in operations and good in implementation. Beside network analysis, the researcher also using catchment area methods, buffer analysis and classification analysis. Buffer analysis used to describe the level of accessibility of households to reach the nearest station.

f. Traffic and road network

Reference (Miller and Storm, 1996) used network analysis as a tools in GIS to represent the multi-modal transportation network to support network equilibrium-based travel demand models. GIS-T become popular in transport studies especially in network analysis because it has several advantages in data modelling, data manipulation, and data analysis that are not achieved by previous GIS (Chen et al., 2011; Thill, 2000) studied to design and implemented a GIS-T data model to representation modal urban transportation network. GIS-T provides several functions and

evaluations to representation of multiple data, identification the shortest-path, coverage of service, route planning, and transportation network analysis (O'Sullivan et al., 2000). Network analysis in GIS also used by (Zhang et al., 2016) to analyse the model results, the factors shortest distance and **shortest travel time in cyclist' routes choice**. The study by (Aljoufie, 2014) used network analysis in GIS to present the simulated pattern of traffic flow and the characteristics of transport system. Furthermore, (Yigitcanlar et al., 2010) used the Sustainable Infrastructure, Land-use, Environment and Transport Model (SILENT) as advanced GIS and indicator-based urban sustainability indexing model. Whereas, the GIS system produces a set of indices in five comparative sustainability levels: Low, Medium-Low, Medium, Medium-High, and High. Then, (Abreha, 2007) used network analysis to identify deficient network elements. The research work conducted by (Al-Ali, 2016) state network analysis in GIS has could be used in establishing urban cycling routes in preventing traffic accidents, designing the road traffic safety evaluation system, road networks, road accident analysis and real-time monitoring, the analysis of the impact of traffic congestion on road accidents, decision analysis in public resource administration and the analysis of causes and consequences of road traffic crashes. The work by (Fedra, 1999) has integrated spatial and GIS parameters and indicators and demonstrated the possible capabilities and applicability of GIS as tools in assessing performance of the transportation system. Whereas (Wang, 2005) explored the integrating of GIS as spatial analysis simulation models to add a temporal dimension and computer visualization to add more options for presentation, all works to support planning process. GIS with overlay analysis used traffic safety by mapping accident location data, performing kernel density analyses and combining the results (Machado et al., 2015). The domination of network analysis of GIS

approach in Traffic and road network seen from previous research. Although supported by methods variation such as SILENT but core of the research still using network analysis in GIS or GIS-T and also classification analysis commonly used in several previous studies.

#### g. Transportation Infrastructure

A study by (Dalumpines, 2008) explores the extraction of urban form/land use information in developing indicators to support Transport Ecological Footprint (TEF) analysing using Remote Sensing and GIS. The useful of GIS in this study to supports handling of spatial data from remotely sensed imagery and integrates it with other images and ancillary data from different sources. GIS also used in overlay analysis between neighborhood and connectivity functions to delivered TEF-linked indicators and used buffer analysis to proximity index 1 km distance from the public road network. Similarly, a study described public transport infrastructure using GIS to present eco-efficiency for public transport infrastructure (Aljoufie and Tiwari, 2016). It is calculated from length of public transport routes in meters divided by geographical area of district in hectares. Then, the paper by (Lopes et al., 2014) used GIS based to spatial regression models to forecast travel demand in correlation with transportation infrastructure supply, also used GIS-T software to analyse the changes produced in the models with the inclusion of spatial variables. Performances of transportation infrastructure also as main factor which affected the sustainable urban transport. Some calculation combined with classification analysis used in this analysis. Buffer analysis is correlated with index impact of transport infrastructure. Table 1 show the matrix of topic research classification based on GIS approach as previous discussion.

**Table 1**  
The matrix of topic research classification based on GIS approach

Topic	Objective	Authors
Accessibility	<ul style="list-style-type: none"> <li>- to identify transportation routes</li> <li>- to calculate and map regional spillovers, economic potential values</li> <li>- to measure of accessibility aggregate to define nearest location</li> </ul>	(Paudel et al., 2009), (Gutierrez et al., 1998), (Mavoa et al., 2012), (Murad, 2003), (Murad, 2004), (Murad, 2005), (Murad, 2008), (Murad, 2011), (A. Murad, 2014), (Chapleau and Morency, 2005), (Ford et al., 2015)
Noise Pollution	<ul style="list-style-type: none"> <li>- to calculate noise pollution area</li> <li>- to model the environmental impacts of different road traffic scenarios.</li> </ul>	(Li et al., 2002), (Brown and Affum, 2002), (Antunes and Santos, 2001), (Valdes et al., 2016)
Energy Consumption	<ul style="list-style-type: none"> <li>- to calculate energy consumption</li> </ul>	(Arampatzis et al., 2004)
Public Transport	<ul style="list-style-type: none"> <li>- to representation of the multimodal transportation network</li> <li>- To presented data in spatial analysis</li> <li>- to presented road network</li> <li>- to assess the level of service of the existing public bus transport system</li> <li>- To identify deficient network elements.</li> </ul>	(Miller and Storm, 1996), (Mavoa et al., 2012), (Abosuliman et al., 2011), (Aljoufie and Tiwari, 2016), (Li et al., 2002), (Valdes et al., 2016)

Topic	Objective	Authors
Traffic and Road Network	<ul style="list-style-type: none"> <li>- to representation of the multimodal transportation network be realistic</li> <li>- to model road network</li> <li>- multiple data representations, shortest-path identification, service coverage, route planning, and transportation network aided analysis</li> <li>- to present the simulated pattern of traffic flow and the characteristics of transport system</li> <li>- to assess the level of service of the existing public bus transport system</li> <li>- to identify deficient network elements.</li> <li>- to analyse the impact of traffic congestion on road accidents</li> <li>- to analyzed traffic safety for vulnerable road users by mapping accident location data</li> <li>- performing kernel density analyses and combining the results</li> </ul>	(Miller and Storm, 1996), (Thill, 2000), (Chen et al., 2011), (Mavoa et al., 2012), (Zhang et al., 2016), (Aljoufie, 2014), (Yigitcanlar and Dur, 2010), (Abreha, 2007), (Al-Ali, 2016), (Fedra, 1999), (Wang, 2005), (Machado et al., 2015), (Valdes et al., 2016)
Transport Infrastructure	<ul style="list-style-type: none"> <li>- as presentation tools to presented result of analysis, with classification analysis</li> <li>- supports handling of spatial data from remotely sensed imagery and integrates it with other images and ancillary data from different sources</li> <li>- to forecast travel demand in collaboration between GIS based and spatial regression models</li> </ul>	(Dalumpines, 2008), (Aljoufie and Tiwari, 2016)

The research topic in SUT performance is dominantly by traffic and road network and accessibility. Then, the average papers about noise pollution, public transport and transport infrastructure. Topic about energy consumption is a few. Fig. 1 shows the papers number used GIS approach in Transport Performance studies.

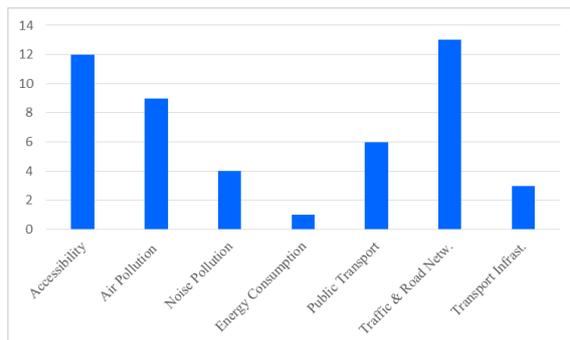


Fig. 1. Number of papers using GIS in Transport Performance

### 3.2 Classification by GIS tools and functions to measure transport performances

#### a. Geocoding

Geocoding denotes to the representation of a **feature's location or address in coordinates (x, y) to be indexed spatially**. For instance, a valid street address can use reverse geocoding converts x, y coordinates. This function allows the address of a mobile user to be displayed once their phone has been located via GPS or cell tower triangulation (Shekhar and Xiong, 2008). In his research, (Murad, 2004) used geocoding in his studies to identify the location health care needs as the data gathered non digitized format. Also, used geocoding to create points on a map from a table of addresses.

#### b. Network Analysis

Network analysis include the basic functions of a GIS. This GIS tools used to measure of accessibility aggregate (O'Sullivan et al., 2000), to define the locations to determine their levels of accessibility (Murad, 2005), to calculate the length of each network link from geometry (Ford et al., 2015), to estimate the main pollutants from road networks (Brown and Affum, 2002), traffic model for traffic flows mapping (Gualtieri and Tartaglia, 1998), traffic simulation and analysis (Arampatzis et al., 2004), presenting road network (Aljoufie, 2016b);(Valdes et al., 2016), to assess the level of service of the existing public bus transport system and to identify deficient network elements (Abreha, 2007).

#### c. Buffer Anaysis

The function of buffer in GIS denote to finding spatial objects that are within a certain distance of an area (Shekhar and Xiong, 2008). Also, buffer analysis used to representation the space-time geography framework isochrones (lines of equal travel time) are a natural way (O'Sullivan et al., 2000), to define the object area based on a defined distance from other object (Murad, 2003), to evaluate the accessibility of any location according to the factor of distance (A. A. Murad, 2014).

#### d. Thiessen Function

As a part of GIS analysis, thiessen function used to have polygon feature data where the area inside the polygon is closer to the point than to any other point (Murad, 2003). **“Thiessen polygons are created around the points to form an exhaustive landscape, with those polygons inheriting all of the overlaying points' attributes”** (Shekhar and Xiong, 2008).

#### e. Straight-line Allocation Function (SLA)

This tools to develop techniques for the optimal location of such central facilities such as schools, fire stations and retail stores (Shekhar and Xiong,

2008). Also, several functions of Straight-line Allocation Function (SLA) i.e. to identify customers/clients served by a service or stores, to identify the closest hospital or health center, to find areas with a shortage of fire hydrants, to locate areas not served by a chain of supermarkets (Murad, 2008).

f. Classification methods

Objects with similar attribute structure can be categorized into classes by this method. For instance, classification method used to identify level of accessibility to health care facilities (A. Murad, 2014) and to identify level of accessibility to health care facilities (Lopes et al., 2014). Table 2 show the matrix of classification GIS tools in previous studies as discussed at below.

The use of GIS tools in reviewed papers is dominantly by network analysis. On regular is using

the buffer analysis, overlay analysis and SLA. While, paper number just a few in thiessen function, quintile analysis and classification methods as shows in Fig. 2.

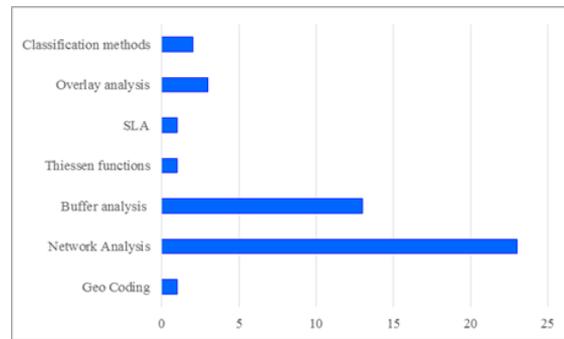


Fig. 2. Proportion of paper used GIS tools to measure urban transport performances

**Table 2**  
The classification GIS use by tools in Transport Performance Studies

GIS Tools	Function	Authors
Geocoding	<ul style="list-style-type: none"> <li>- to identify the location of place in the map.</li> <li>- to create points on a map from a table of addresses</li> </ul>	(Murad, 2004)
Network Analysis	<ul style="list-style-type: none"> <li>- to define the locations to determine their levels of accessibility.</li> <li>- to calculate the length of each network link from geometry.</li> <li>- to estimate the main pollutants from road networks.</li> <li>- traffic model for traffic flows mapping</li> <li>- traffic simulation and analysis</li> <li>- presenting road network</li> <li>- to assess the level of service of the existing public bus transport system</li> <li>- to identify deficient network elements</li> </ul>	(Paudel et al., 2009), (Gutiérrez et al., 2010), (Mavoa et al., 2012), (Murad, 2005), (Chapleau and Morency, 2005), (Ford et al., 2015), (Miller and Storm, 1996), (Thill, 2000), (Chen et al., 2011), (Mavoa et al., 2012), (Zhang et al., 2016), (Aljoufie, 2016a), (Yigitcanlar and Dur, 2010), (Abreha, 2007), (Al-Ali, 2016), (Fedra, 1999), (Wang, 2005), (Machado et al., 2015), (Brown and Affum, 2002), (Armstrong and Khan, 2004), (Gualtieri and Tartaglia, 1998), (Arampatzis et al., 2004), (Brown and Affum, 2002), (Miller and Storm, 1996)
Buffer analysis	<ul style="list-style-type: none"> <li>- the space-time geography framework. isochrones (lines of equal travel time) are a natural way.</li> <li>- to define the object area based on a defined distance from other object</li> <li>- to evaluate the accessibility of any location according to the factor of distance</li> </ul>	(Mavoa et al., 2012), (Murad, 2003), (A. A. Murad, 2014), (Chapleau and Morency, 2005), (Abreha, 2007), (Antunes and Santos, 2001), (Alshuwaikhat and Aina, 2006), (Gualtieri and Tartaglia, 1998), (Paudel et al., 2009), (Chapleau and Morency, 2005), (Murad, 2008), (Murad, 2011)
Thiessen functions	<ul style="list-style-type: none"> <li>- to have polygon feature data where the area inside the polygon is closer to the point than to any other point</li> </ul>	(Murad, 2003)
Straight-line Allocation Function (SLA)	<ul style="list-style-type: none"> <li>- to identify customers/clients served by a service or stores;</li> <li>- to identify the closest hospital or health center;</li> <li>- to find areas with a shortage of fire hydrants;</li> <li>- to locate areas not served by a chain of supermarkets</li> </ul>	(Murad, 2008)
Overlay analysis	<ul style="list-style-type: none"> <li>- to have a GIS layer that have patient data and facilities catchment area,</li> <li>- to get a layer that have district data such as population size and proximitst health centres.</li> </ul>	(Murad, 2003), (Murad, 2004), (Murad, 2008)

GIS Tools	Function	Authors
	- designated as "intersect" for the new catchment areas and for the city districts' coverage.	
Classification methods	- to identify level of accessibility to health care facilities - to present multiple regression model of spatial distribution	(A. A. Murad, 2014), (Lopes et al., 2014)

#### 4. Conclusion

This paper aims to review of the literature on the use of Geographic Information System (GIS) for measuring sustainable urban transport performance. 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 GIS application in urban transport performance studies consist of seven classifications: accessibility, air pollution (emission), noise pollution, energy consumption, public transport, traffic and road network. This paper shows the use of GIS in Sustainable Urban Transport (SUT) performance is dominantly on traffic and road network studies while the usage GIS tools is dominantly by network analysis.

Based on these studies, classification and analysis of the journals, some idea for next research are founded. Assessment of urban transport in previous research mostly not involve the sustainability paradigm in measuring its performance and the concern in urban transport sustainability using comprehensive indicators is still rare. Therefore, it is interesting that how to know GIS - as quantitative research - could be use measure performance of sustainable urban transport to be more comprehensive with involve its indicators and other aspects such as: data, people, software and hardware.

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