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Applicability of GIS tools in assessing performance of the transportation systems in urban areas

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Abstract

Purpose – The purpose of this paper is to investigate applicability of geographical information system (GIS) tools in assessing performance of the transportation systems which integrate spatial and GIS parameters and indicators.

Design/methodology/approach – In this context, performance measures have been objectively related to the strategic goals and objectives identified by policy makers in particular areas.

Findings – Results suggest that as a result of on the characteristics of transportation system, further understanding and considerations have been achieved regarding the performance of the investigated transportation systems and the needed transport polices in the study areas.

Originality/value – The integrating of spatial data with the conventional data to assess performance of the transportation system.

Keywords GIS, Performance indicators, Geographical information system, Transport safety

Paper type Research paper

Introduction

A geographical information system (GIS) is a system of specialised information in the input, management, analysis and transmission of geographic information (spatially related). Among a wide range of potential applications, GIS can be used in transportation problems and has received a lot of attention. The particular branch of GIS applied to transportation issues is described as the geographic information systems for transportation (GIS-T) (Rodrigue *et al.*, 2006).

GIS are becoming common place in several applications. They have been used in various industries for more than a decade. The focus in this research is mainly in two sectors: transportation and security. In transportation, desktop mapping and analysis tools have been a major commercial market for many industries. There are many new hardware devices that enable mobile geospatial services. GIS has been used in transportation management, planning and modelling (Berglund, 2001; Gholston and Anderson, 2005; Prasad, 2003), in establishing urban cycling routes in preventing traffic accidents (Noland and Quddus, 2004), in designing the road traffic safety evaluation system, in road networks (Lagunzad and Mcpherson, 2003), for solid waste disposal (Ghose *et al.*, 2006), in road accident analysis and real-time monitoring (Mahmud and Zarrinbashar, 2008), in the analysis of the impact of traffic congestion on road accidents (Wang *et al.*, 2009), for decision analysis in public resource administration (Kepner *et al.*, 2002), and in the analysis of causes and consequences of road traffic crashes. In security, GIS is used in supporting homeland security, in border demarcation (Meha and Selimi, 2010), to overcome non-traditional security (Soomro *et al.*, 2009) and in securing the Olympics.

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The concept of GIS in transportation

GIS-T refers to the applications and principles of GIS-T to transportation problems. GIS-T research focuses on how GIS can be further developed and enhanced in order to meet the needs of transportation applications and investigates in how GIS can be used to facilitate and improve transportation studies such as:

- data representations are the various elements of transport systems to be represented in a GIS-T;
- analysis and modelling of the methodologies of transport used in GIS-T; and
- applications, the types of applications are particularly suitable for GIS-T.

GIS is rapidly being developed and applied in a no-limit list of applications. Planning in general, and transportation in particular, have greatly benefited from some very effective and efficient technology. Some of the specific transportation applications of GIS include road design, highway mapping and analysis of accident data and traffic volumes (Balaji and Ganesh, 2003; Condeço-Melhorado *et al.*, 2011). GIS is widely used in transportation planning and highway maintenance and management in many developed countries. GIS offers transport planners and designers a medium for analysing and sorting data on density of applications, land uses and travel behaviour. The main objectives using GIS are data integration and map display. These uses can be addressed through a GIS application more effectively, efficiently and economically. Lack of appropriate and correct data for GIS remains the main problem, as GIS describes a world in terms of geographical coordinates and other projection systems of graphical objects.

GIS requires building and maintaining of a database, selecting and upgrading hardware and software, using updated technology to solve problems, networking, providing access and others (Rodrigue *et al.*, 2006). GIS functions include statistics, charting, decision support systems, modelling and access to travel databases. The four important elements of GIS to work for transportation are encoding, management, analysis and reporting. Any GIS data or information is stored and represented as layers, as it is a geographical feature associated with their attributes.

Conventional principles of transport modelling

Conventional transport planning tends to focus on a limited set of evaluation criteria (the factors considered in the planning process), such as facility costs, travel speeds, vehicle operating costs and distance-based crash risk. Other impacts tend to receive less consideration. Some of these omissions reflect impacts that are difficult to quantify, such as social equity and indirect environmental impacts, but others are ignored simply out of tradition (parking costs, long-term vehicle costs, construction delays). These omissions tend to favour mobility over accessibility, and automobile travel over other modes (Litman, 2013).

Conventional transport modelling is used to develop information to help make decisions on the future development and management of transportation systems, especially in urban area. It is used as a part of transportation planning. The transport model is a series of mathematical equations used to represent how choices are made when people travel. Some models are complex and require the processing of large sets of data. GIS has minimised many of the drawbacks to conventional transport modelling. Early network models were topically accurate but lacking in topographic accuracy (Kutz, 2003). Topographically accurate representation is needed for producing recognisable network maps and for certain types of proximity analysis. In addition, most large-scale network models utilise shape points. This mean much more data storage is required (Kutz, 2003).

Key performance indicators (KPIs) are performance measurement which define a set of values used to measure against. The raw sets of values are called indicators. Indicators can be quantitative (usually as a number), practical (that interface with existing company processes), directional (specifying whether an organisation is getting better or not), actionable (make a change) or financial. In other words, KPIs, are objectives to be targeted that will add the most value to the business. They prove to be very useful for business and organisations. They are agreed to beforehand, to reflect the critical success factors of an organisation. They will differ depending on the organisation (Haeckel, 1999).

KPIs usually are long-term considerations. The definition of what they are and how they are measured do not often change. The goals for a particular KPI may change as the goals change. An example of a KPI is body temperature. It is measured the same way by everyone, easy to collect and record, a critical indicator of health and it helps with diagnosis (if fever, investigate why and if no fever investigate different symptoms).

KPI are designed for senior management, while metrics (to manage service) are designed for management tracking, and statistics are designed for daily service management. In business, possible components for a KPI are: volume (transactions, page views and searches), cost, timeliness, quality, customer satisfaction. KPIs are defined in this research as the measures that provide decision makers and policy people with the most important performance information about the transportation system in order to enable them to assess the performance level of the system. KPIs should clearly link to the strategic objectives of the organisation and therefore help monitor the implementation of the transport strategy. A further set of spatial performance indicators (SPI) which integrated spatial and GIS data have also been developed and tested in this research.

Data collection

In this paper, the city of Edinburgh, which is the capital city of Scotland in the UK and the seat of the Scottish Government and the Scottish Parliament is studied with regard to the performance of its transportation system and safety. Edinburgh is well known for its ancient and historic listed architectural buildings, and it serves as one of Europe's cultural and historical centres, with the city's Old Town and New Town dating back to the eighteenth century. The city of Edinburgh serves as the financial hub of Scotland and one of the fastest growing economies in the UK. The economy of Edinburgh is mostly centred on banking and finance, hospitality, services and education – Edinburgh has four universities.

This is a city that has one of the fastest growing economies in Scotland and the UK within the past decade. The economic growth has also attracted more people from outside Edinburgh to work in the city, mostly travelling by car. The number of households in the city of Edinburgh that do not have access to a car or do not have a car was less than Glasgow and Dundee and above the Scottish national average of 34 per cent. Glasgow recorded 51 per cent and Dundee recorded 42 per cent compared with almost 40 per cent of the households in Edinburgh having no access to a car. This indicates that nearly 60 per cent of the households in Edinburgh own or have access to a car or van.

Over the last three decades car ownership for the residents in the city of Edinburgh has nearly doubled from 94,000 cars in 1981 to 181,000 cars in 2011, resulting in an increase of about 48.07 per cent cars in the last three decades. About 60.1 per cent of the households in Edinburgh own one or more cars or vans and 66.4 per cent of the households in both Edinburgh and the surrounding Lothian own cars or vans compared with the Scottish average of 69.5 per cent of household car ownership level. Fewer residents in Edinburgh drove to work in 2011 (i.e. based on place of residence) compared to 2001 in spite of the increase in car ownership over the last decades. However, car journeys into Edinburgh have increased significantly due to large growth in car travel in some of the neighbouring local authority areas resulting in heavy traffic and congestion in some parts of the city. Car ownership and use have always been blamed for contributing towards increasing accidents and worsening safety.

The city of Edinburgh council recognises that the most productive way to embark on many trips is by the use of car, but car journeys also come with heavy traffic and congestion. In managing car use and the associated traffic congestion in the central business district, Edinburgh council has implemented measures such as parking management in some areas, car club promotions, given support for priority for "high occupancy vehicles" and car sharing for people going to similar places to try to encourage efficient car use in order to reduce car usage and traffic congestion.

Safety and accident records are under great scrutiny from the city council and nationally. There is a large number of studies and investigations which explore locations, factors, areas and policies which are aiming at improving safety and reducing accidents in the city. Most of these studies, however, are concentrated on one dimension. For example, road factors are often investigated by the council. Psychological, geographical and other factors have also been discussed by other investigators. What is missing, however, is an approach which integrates all the inputs and outcomes from such investigations into a study which can then become a more useful source of information for decision and policy makers.

Edinburgh and the neighbouring towns have been chosen as the study area for this research. The study area has a mixed traffic flow, mixed traffic lanes in some part of the route, traffic congestion during the peak hour periods and the free flow traffic mostly at the outer parts of the city leading to the neighbouring towns and cities. Some parts of the study area have higher flow rates, denser road network, higher accident rates, population density and other transport, geographical and traffic characteristics. This usually results in different accident rates and severities in different areas. The study area has different speed limits that range from 20 mph (32 km/h) in the inner city to 70 mph (113 km/h) maximum in the outer city's trunk roads. The different speed limits within the study area enable different car-following driving behaviours to be observed. There is a mix of single and double lanes on the study routes which all vehicle types are allowed to use. The study area also has heavy commercial activities within the inner city as well as shopping malls and universities along some of the routes which contribute to the flow of traffic on the corridor. Four zones have been selected from Edinburgh city. These are discussed below.

The A720 (The Edinburgh City Bypass) and A1 are two major roads that surround Edinburgh and serve as the boundary between Edinburgh and its neighbouring towns. The A90, A902 and A199 connect the A720 at the north west of the city to the A1 at the north east of the city, making the A720, A1, A90, A902 and A199 the main trunk roads forming a ring road around the city of Edinburgh. The A7, A8, A70, A71, A701, A702 and A900 are the main arterial roads that connect to the trunk roads to the neighbouring towns and cities. Because of the city's historical nature and buildings in the Old and New Towns, the roads in the inner part of Edinburgh are quite narrow. Some of the roads in Edinburgh are quite steep due to the hilly nature of some parts of the city which may affect the speed of vehicles. Edinburgh has different speed limits for vehicles across the city with the speed limits ranging from 20 mph (inner city and some residential areas) to 40 mph maximum (outer city).

Car usage, public transport and safety issues in Edinburgh

The main form of public transport in Edinburgh is buses. There are two bus companies in Edinburgh: Lothian Buses, the largest operator (operates in the city of Edinburgh Council and the neighbouring councils) and First Bus, which also operates services to/from outlying towns. The city attracts one million overseas visitors a year, making it the second most visited tourist destination in the UK, after London. In 2009 YouGov poll, Edinburgh was voted the "most desirable city in which to live in the UK". Edinburgh was also rated "The best place to live in Channel 4's 2007" Homes survey. It is ranked as a gamma-world city by the Globalisation and World Cities Research Network.

Lothian Buses operate the majority of city bus services within the city and to surrounding suburbs, with the majority of routes running via Princes Street. Services further field operate from Edinburgh Bus Station off St Andrew Square. Lothian Buses, as the successor company to the city's Corporation Trams, also operates all of the city's branded public tour bus services, the night bus network and airport buses. Lothian Buses's Mac Tours subsidiary has one of the largest remaining fleets of ex-London Routemaster buses in the UK, many converted to open top tour buses. In 2007, the average daily ridership of Lothian Buses was over 312,000 – a 6 per cent rise on the previous year.

Following parliamentary approval in 2007, construction began on a new Edinburgh tram network in early 2008. The first stage of the project was expected to be operational by July 2011 but did not start until the second half of 2014. The first phase is now operational and the trams are running from the airport in the west of the city, through the centre of Edinburgh. The next phase of the project will see trams run from Haymarket through Ravelston and Craigleith to Granton on the waterfront. Future proposals include a line going west from the airport to Ratho and Newbridge, and a line running along the length of the waterfront.

Investigation of Edinburgh city transportation system performance

Edinburgh and the neighbouring towns have been chosen as the study area for this research. The study area has a mixed traffic flow, mixed traffic lanes in some parts of the route, traffic congestion during peak hour periods and free flow traffic mostly at the outer part of the city leading to neighbouring towns and cities. Some parts of the study area have higher flow rates, denser road networks, higher accident rates, population density and other transport, geographical and traffic characteristics. This usually results in different accident rates and severities in different areas. The study area has different speed limits that range from 20 mph (32 km/h) in the inner city to 70 mph (113 km/h) maximum in the outer city's trunk roads. The different speed limits within the study area enable different car-following driving behaviours to be observed. There is a mix of single and double lanes on the study routes which all vehicle types are allowed to use. The study area also has heavy commercial activities within the inner city as well as shopping malls and universities along some of the routes which contribute to the flow of traffic on the corridor. Four zones have been selected as below:

(1) Zone 1. 60QP003975.
(2) Zone 2. 60QP003178.
(3) Zone 3. 60QP000041.
(4) Zone 4. 60QP001221.

The codes provided is an output area within Scotland. This information provided has been obtained through Google. For example, the output area 60QP003975 consisting of Edinburgh, city of postcodes EH1 1BN, EH1 1BP, EH1 1BQ, EH1 1BS, EH1 1BX, EH1 1DE, EH1 1DF, EH1 1PB and so on.

Transport safety performance indicators are the measurement that is causally related to crashes or injuries, used in addition to an account of crashes or injuries in order to indicate safety performance that leads to accidents. Transport safety is a main priority in the common transport policy and a high level of protection for the country's citizens. Policy makers and managers aiming for a higher level of safety take note of the factors influencing safety and those factors they are able to affect or control. Safety performance indicators provide ways by which policy makers can ensure that the actions are really effective and represent the best use of public recourse. The following KPIs have been proposed and investigated for each zone to be used in the investigation:

- safety performance indicators;
- public transport performance indicators; and
- traffic performance indicators.

These KPIs have been integrated with the GIS system characteristics during the modelling stage to represent the performance of the transport system in the city of Edinburgh. The following SPIs have been used in the modelling:

- number of accidents per time;
- number of accidents per population;
- number of accidents per road type;
- number of bus routes per time;
- number of routes per population;
- number of routes per road type;
- traffic volume per time;

- traffic volume per population; and
- traffic volume per road type.

Several sources have been used for each of the two case studies. For the Edinburgh case study, three groups of data sets were selected and relevant performance indicators have been analysed. These include STATS19 data, as well as other traffic data.

Results and conclusions

The main aim of the paper has been to investigate the capabilities and applicability of GIS tools in assessing performance of the transportation systems which integrate spatial and GIS parameters and indicators. In order to achieve this, a number of performance measures have been identified and objectively related to the strategic goals and objectives identified by policy makers in the study area; Edinburgh city in this case.

A number of performance indicators have been identified to be used to assess the performance of the transport system in Edinburgh. Three KPIs have been gathered as presented in below: accident data, transport system characteristics and traffic volume data. The relevant KPIs for accident data are: number of accidents per time a year, number of accidents per population and number of accidents per road length. The KPIs for transport system characteristics are: number of buses routes per area size, number of buses routes per population and number of buses routes per road length. The KPIs for traffic volumes are: the traffic volume per area size, traffic volume per road length and traffic volume per number of junctions. Accident data were obtained from STATS19 data, in which accidents involving serious injury are reported by the police. STATS19 provides details of personal injury accidents.

In terms of characteristics of the public transport systems, a number of performance indicators have been identified to be used to assess the performance of the transport system in Edinburgh. Three groups of data sets and relevant performance indicators are gathered, and are summarised in Table I.

The investigation presented in the paper demonstrate the possible capabilities and applicability of GIS as a tools in assessing performance of the transportation systems which integrate spatial and GIS parameters and indicators. Further work in this area and further applications to other urban areas are recommended.

Data sets	Accident data	Transport system characteristics data	Traffic volume data
Performance indicators	Number of accidents/year Number of accidents/population Number of accidents/road length	Number of buses routes/area size Number of buses routes/population Number of buses routes/road	Traffic volume/area size Traffic volume/road length Traffic volume/number of junctions

Table I.
Data sets and relevant performance indicators

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