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An operational indicator for network mobility using fuzzy logic

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ABSTRACT

This paper proposes a fuzzy logic model for assessing the mobility of road transport networks from a network perspective. Two mobility attributes are introduced to account for the physical connectivity and road transport network level of service. The relative importance of the two mobility attributes has been established through the fuzzy inference reasoning procedure that was implemented to estimate a single mobility indicator. The advantage of quantifying two mobility attributes is that it improves the ability of the mobility indicator developed to assess the level of mobility under different types of disruptive events.

A case study of real traffic data from seven British cities shows a strong correlation between the proposed mobility indicator and the Geo distance per minute, demonstrating the applicability of the proposed fuzzy logic model. The second case study of a synthetic road transport network for Delft city illustrates the ability of the proposed network mobility indicator to reflect variation in the demand side (i.e. departure rate) and supply side (i.e. network capacity and link closure). Overall, the proposed mobility indicator offers a new tool for decision makers in understanding the dynamic nature of mobility under various disruptive events.

1. Introduction

Mobility is essential to economic growth and social activities, including commuting, manufacturing and supplying energy (Rodrigue, Comtois, & Slack, 2009). Higher mobility (or in other words, a better ability of the network to deliver an improved service) is a very important issue for decision makers and operators as it relates to the main function of the road transport network. Consequently, an assessment of road transport network mobility is essential in order to evaluate the impact of disruptive events on network functionality and to investigate the influence of different policies and technologies on the level of mobility. Disruptive events may be classified as manmade or climate change related events, the scale of which will also have an impact on road transport network mobility. For example, a small accident may lead to the closure of one lane of a local road or a major accident may cause the closure of a motorway for several hours, with cascading effects on the entire network. Climate change related events (e.g. floods, inclement weather and heavy snowfall) have seen significant increase with resulting impacts on the road transport network. As an example, at the European level, the financial cost of network interruption from extreme weather is estimated to be in excess of €15 billion (FEHRL, 2004) whereas, in the USA, the estimated network repair costs due to snow and ice is 5 bn US$ (Enei et al., 2011).

Mobility could have two dimensions (Berdica, 2002). Firstly, mobility as "the ability of people and goods to move from one place (origin) to another (destination) by use of an acceptable level of transport service" – commonly measured by vehicle kilometres and evaluated through surveys (Litman, 2008). Secondly, from the road transport network prospective, mobility is defined as the ability of a road transport network to provide access to jobs, education, health service, shopping, etc., therefore travellers are able to reach their destinations at an acceptable level of service (Hyder, 2010; Kaparias & Bell, 2011). Therefore, mobility is a measure of the performance of the transport system in connecting spatially separated sites, which is normally identified by system indicators such as travel time and speed. However, here the mobility concept is used as a key performance indicator to measure the functionality of the road network under a disruptive event, as in the second case above. It is therefore used to reflect the ability of a network to offer users a certain level of service in terms of movement.

The main objective of this study is to develop a single mobility indicator based on two mobility attributes using the fuzzy logic approach. Two case studies are considered to validate the technique: the first case based on real traffic data between seven British cities and the second case study concerned with a synthetic road transport network for Delft city.

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2. Mobility assessment

As with many transport concepts, there are no universally agreed indicators to assess road transport network mobility from a network prospective. According to the National Research Council (2002), mobility assessment should take into account system performance indicators such as time and costs of travel. They propose that the mobility level is inversely proportional to variations in travel time and cost, whereas, Zhang, Wen, and Jin (2009) suggested that travel time and average trip length are two key indicators to evaluate system mobility. The study by Zhang et al. (2009) developed a performance index to evaluate the mobility of an intermodal system, measured by the ratio of travel speed to the free flow speed weighted by truck miles travelled. However the performance index could be adapted to measure road transport mobility by considering total traffic flow rather than average daily truck volume. In line with this approach, Wang and Jim (2006) used the average travel time per mile as a mobility indicator, where the distance is the Geo distance rather than actual distance travelled. The use of the Geo distance rather than travel distance could lead to an overestimation of mobility as the Geo mileage is generally shorter than the actual travel distance between two locations.

Cianfano et al. (2008) suggested a number of indicators based on link travel time and speed to evaluate road network mobility. Specifically, they (Cianfano et al., 2008) introduced a vehicle speed indicator, *VSI*, measuring the variation in speed compared to free flow conditions. A value of *VSI* of 1 would indicate that vehicles are experiencing a travel speed across the network equal to the free flow speed (i.e. the average free flow speed of the network). Under extreme conditions $VSI = 0$ indicates a fully congested road network. Cianfano et al. (2008) also proposed a mobility indicator based on travel time. According to Lomax and Schrank (2005), transport performance measures based on travel time fulfil a range of mobility purposes. However, other researchers (Cianfano et al., 2008; Zhang et al., 2009) have used simple and applicable indictors that could be easily implemented at a real-life network scale. They only considered the impact of traffic flow conditions (presented as the variation in travel speed compared with free flow speed) and took into account the impact of unconnected zones. If some links are not available (e.g. closed due to an incident) they are omitted from the indicator calculations, producing misleading values.

Murray-Tuite (2006) proposed a number of indicators to estimate mobility under disruptive events, some of which were scenario based measures such as the time needed to vacate a towns' population and the capability of emergency vehicles (ambulance, police) to pass from one zone through to another. Murray-Tuite (2006) also suggested that the average queue time per vehicle, the queue length on the link and finally, the amount of time that a link can offer average speeds lower than its nominal speed limit could also be considered as mobility indicators.

Chen and Tang (2011) introduced the notion of link mobility reliability, calculated using a statistical method based on historical data i.e. speed data for 3 months derived from floating cars. They also investigated the possible influencing factors on mobility reliability. Their results showed that the mobility reliability of an urban road network is correlated with network saturation (volume/capacity ratio) and road network density.

At the operational level, TAC (2006) carried out a survey including Canadian provincial and territorial jurisdictions regarding current practices in performance measurement for road networks related to six outcomes including mobility. The study found that average speed and traffic volume are widely used as measures of mobility. The study also found that the concepts of accessibility and mobility are used interchangeably in practice, which could conflict with academic practice, where accessibility and mobility are very different concepts. For example, Gutiérrez (2009), emphasised that the mobility concept relates to the actual movements of passengers or goods over space, whereas accessibility refers to a feature of either locations or individuals (the facility to reach a destination). In other words, accessibility could be defined as the potential opportunities for interaction (Hansen, 1959) that are not only influenced by the quality of the road transport network, but also by the quality of the land-use system (Straatemeier, 2008). Widespread communication technologies could play a crucial role in virtual accessibility (Janelle & Hodge, 2000).

Table 1
Linguistic expressions and corresponding values of mobility indicators (Hyder, 2010).

Mobility indicator	Low	Medium	High
Maximum volume/capacity	>75%	50–75%	<50%
Maximum intersection delay	>300 s	60–300 s	<60 s
Minimum speed	<25 kph	25–50 kph	>50 kph

A number of further mobility indicators have been reported, namely, origin–destination travel times, total travel time, average travel time from a facility to a destination, delay per vehicle mile travelled, lost time due to congestion and volume/capacity ratio (TAC, 2006). Meanwhile, Hyder (2010) suggested three indictors to measure the mobility of the road transport network, namely, maximum volume/capacity ratio, maximum intersection delay and minimum speed. The study (Hyder, 2010) used linguistic expressions to evaluate the indicators (as shown in Table 1) and suggested that mobility is gauged by the lowest value of these indicators.

However none of this existing research has considered the impact of the road transport network infrastructure, such as road density, on network mobility. Therefore, the research presented here considers the impact of network infrastructure and network configuration using graph theory measures alongside traffic conditions indicators, as discussed above. The use of the network configuration and traffic flow conditions will reflect the impact of different kinds of disruptive events. For example, in case of a flood, some parts of the network could become totally disconnected whilst other parts of the network could benefit from lower network loading. Therefore the impact of such an event could be masked if the mobility indicator only considers traffic conditions. In the case of adverse weather conditions the overall network capacity could decrease (Enei et al., 2011) leading to congested conditions, but not necessarily affecting travel distance. Consequently, the consideration of both attributes i.e. physical connectivity and traffic conditions, is necessary to cover both cases. In Section 3 below, mobility attributes are introduced.

3. Mobility modelling of road transport networks

In the research here, the mobility concept is treated as a performance measure expressing the level of road transport network functionality under a disruptive event. Therefore, mobility is used as a concept to reflect the ability of a network to offer its users a certain level of service in terms of movement. To obtain a single mobility indicator a number of mobility attributes are used to capture a range of mobility issues, as outlined above.

3.1. Mobility attributes

Based on the definition of mobility (i.e. the ability of the road transport network to move road users from one place to another with an acceptable level of service), two attributes are proposed. Firstly, an attribute is used to evaluate physical connectivity, i.e. the ability of road transport to offer a route to connect two zones.