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Remoteness and accessibility in the vulnerability analysis of regional road networks

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ABSTRACT

This paper considers the development of a method for network vulnerability analysis which considers the socio-economic impacts of network degradation and seeks to determine the most critical locations in the network. The method compares the levels of remoteness (or its inverse, accessibility) of localities within the study region, on the basis of the impacts of degradation of the road network on a recognised accessibility/remoteness index that can be applied to each and every location within the region. It thus extends the earlier work on accessibility-based vulnerability analysis which was limited to assessment of impacts on selected nodes in a network. The new method allows study of impacts on both specified locations (which do not have to be represented as network nodes) and the region as a whole. The accessibility/remoteness index is defined so that an accessibility surface can be calculated for the region, and the volume under this surface provides an overall measure of accessibility. Changes in the volume under different network states thus reflect the overall impacts. The method is applied to a rural region in south east Australia.

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1. Introduction

Network vulnerability emerged as a significant area for in transportation planning research over the last decade. While the main driver was the need to consider the performance and impacts of degraded networks, vulnerability analysis became important for researchers for two reasons: (1) the development of concept and theory regarding vulnerability, and (2) the application of the new theory to large-scale, complex transportation networks, usually (but not exclusively) road networks. The degree of complexity of real world networks requires computation efficiency as well as theoretical development for the implementation of vulnerability analysis. The theoretical developments are therefore grounded in realism.

In broad terms, network vulnerability deals with the socio-economic impacts and transport systems performance of degraded transport networks. Thus network vulnerability is not just an interesting topic for research by transport network modellers; it is also of great importance to modern society. Degraded network performance from system failures, disaster situations or even traffic congestion can have significant social and economic impacts. Network failures, whether full or partial or whether due to natural or man made events, are of great significance. These failures can range from disasters such as earthquakes and bridge collapses, whose effects may persist for long periods of time, to incident based congestion episodes of relatively short duration but still with large social and economic impacts. Transport agencies need well defined concepts and validated models and tools to test networks for their robustness and resilience to failure at different locations, as an integral part of network design and incident management planning, and indeed planning for emergencies.

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This paper describes the development and application of a method for transport network vulnerability analysis, based on considerations of the socio-economic impacts of network degradation, and which seeks to identify the most critical locations in a network. Critical locations in a network may be taken to be those that show the most severe (socio-economic) impacts of failure at those locations. The method therefore considers vulnerability assessment in terms of a planning systems process in which the performance of network components is tested against established performance criteria, and accounting for risks and consequences associated with failures at different locations.

2. Development of vulnerability analysis

Vulnerability analysis emerged as a branch of transport network reliability. Network reliability itself rose to prominence in the mid 1990s and has continued thereafter (e.g. Lam, 1999; Bell and Cassir, 2000; Iida and Bell, 2003; Nicholson and Dantas, 2004). Network reliability research has tended to focus on congested urban road networks and the probability that a network will deliver a required standard of performance. The realisation that there are other issues as well, especially when considering the wider implications of transport systems performance, led to considerations of network vulnerability and the identification of critical infrastructure locations. If the wider social and economic consequences of network failure or degradation are of concern, then 'vulnerability' of the network can be more important than 'reliability', given the latter's focus on transport network performance alone.

The concept of network vulnerability relates to the consequences of failure of some component of the network, such as a link or node, irrespective of the probability of failure. As discussed by D'Este and Taylor (2001), even if the probability of component failure is low and the effect on overall network performance may be small, in some cases the social and economic impact on particular groups in society may be sufficiently large to indicate a major problem warranting remedial action. Low probability of occurrence may not offset the consequences of a network failure. Thus, while network reliability and vulnerability are related concepts, reliability focuses on connectivity and probability whereas vulnerability is about network weakness and consequences of failure.

One substantial development has been the use of accessibility indices as metrics of vulnerability, so that a standard measure of accessibility (e.g. Niemeier, 1997) may be used to assess the likely impacts of network degradation. As an indication of its significance, this concept was introduced *independently* by Berdica and Eliasson (2004), Husdal (2004) and Taylor and D'Este (2004) at the *Second International Symposium on Transportation Network Reliability* (Nicholson and Dantas, 2004). Subsequently there has been growing interest in accessibility metrics as indicators of network performance and vulnerability (e.g. Chen et al., 2007; Taylor et al., 2006; Taylor, 2007; Taylor and D'Este, 2007; Kurauchi et al., 2009).

3. Principles for vulnerability analysis

The broad utility of vulnerability analysis is that accessibility-based metrics can explicitly consider the interaction between a degraded network and the overall travel behaviour of network users. Chen et al. (2007) suggested that consideration of vulnerability using a travel demand modelling approach can indicate the consequences of both demand and supply changes in the network and the potential impacts on travel behaviour.

3.1. Definitions

The starting point for a definition of network vulnerability was provided by Berdica (2002), for whom road network vulnerability was seen as *a susceptibility to incidents that can result in considerable reductions in road network serviceability*. Subsequent researchers have attempted to add more precision, and to indicate the connection between vulnerability and the concept of risk, with its two components of probability and consequence, e.g. D'Este and Taylor (2003) and Nicholson and Dalziell (2003). The identification of critical locations in a network then becomes a major concern.

3.2. Critical locations and infrastructure

Murray and Grubesic (2007) discussed the general concepts of critical infrastructure locations and the needs for identification of both critical locations and associated risks of failure or degradation. Berdica and Mattsson (2007) considered critical locations in terms of known bottlenecks and restrictions, such as bridges providing access to a city centre across a body of water.

In terms of transport networks, primarily road networks, Jenelius et al. (2006) sought to identify critical links in terms of measures of link importance and location exposure, so that both the intensity of impact from an individual link failure and the region affected by the failure could be determined. Their importance and exposure metrics are defined in terms of increases in generalised cost of travel for journeys in degraded networks. Similarly Scott et al. (2006) introduced a Network Robustness Index, for evaluating the critical importance of given network links in terms of the change in travel time (or generalised cost) associated with rerouting all traffic in the system should that link become unusable. The requirement for realistic use of the index was the ability to model realistic network flows and travel behaviour. This requirement was also highlighted by Berdica and Mattsson (2007), especially for congested networks.

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