Real time coupled network failure modelling and visualisation

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Summary

This paper, presents an approach to real-time spatio-temporal analysis of infrastructure network performance by developing an open source geovisualisation tool coupled with infrastructure network failure models in order to simulate, visualise and analyse how spatial infrastructure networks respond over time to major perturbations and failures.

KEYWORDS: Network, geovisulisation, failure modelling, real-time simulation

1 Introduction

Exploring how geospatial networks behave in near real time is becoming increasingly relevant to a number of sectors and a range of different applications, including transport planning and for infrastructure systems engineering to understand potential hazards (Leu et al., 2010). The spatial distribution, time dynamics and attributes of the flows on such networks leads to an information "richness" that makes analysing network behaviour a valuable exercise (Tominski et al., 2012). However, understanding the spatio-temporal flows across a network is not straight forward using traditional static graphs and diagrams as they fail to capture the intrinsic dynamics of these systems (Adrienko and Adrienko, 2011). Geovisualisation technologies offers considerable potential in this regard, not only for the single point-in-time assessment of network performance, but also in terms of recognising and understanding the often hidden patterns of network evolution over time and space that lead to particular configurations of interest.

Real-time geovisualisation of network dynamics is particularly important in assessing the vulnerability of critical spatial infrastructure networks to perturbations. While significant progress has been made in developing graph-theoretic failure models for complex infrastructure networks, these often characterise the failure dynamics of a network in topological terms (Bompard et al., 2011; Boccaletti et al., 2006). While informative, this approach offers little insight into the explicit vulnerability of the network as a function of its spatial structure, or an obvious means by which to understand the temporal dynamics of the infrastructure network failure. In this paper, we present an approach that addresses the lack of real-time spatio-temporal analysis of infrastructure network performance by developing an open source geovisualisation tool coupled with infrastructure network failure models to simulate, visualise and analyse how spatial infrastructure networks behave over time.

2 Coupled network simulation and geovisualisation tool

2.1 Network model parameterisation

The tool has been developed in python using NetworkX (NetworkX, 2014) and can be run using either a static shapefile, or a spatial network stored in a separately developed interdependent spatial network database schema (Barr *et al.*, 2013) as input. The input data generates a network instance attached to which are the flow/movement attribute values of interest, such as time, distance or cost, while a separate set of node and edge classes are used to record/store dynamic attributes that represent the evolving response of the system(Figure 1). The flows and movements assigned consist of a start time, start node and end node and thus form origin-destination pairs. Initial routes between origin-destination pairs are generated by calculating the weighted shortest or least cost path. The assignment of flows and their corresponding start time allows, at the simulation stage, the dynamics of how flows are affected spatially over time to be investigated.

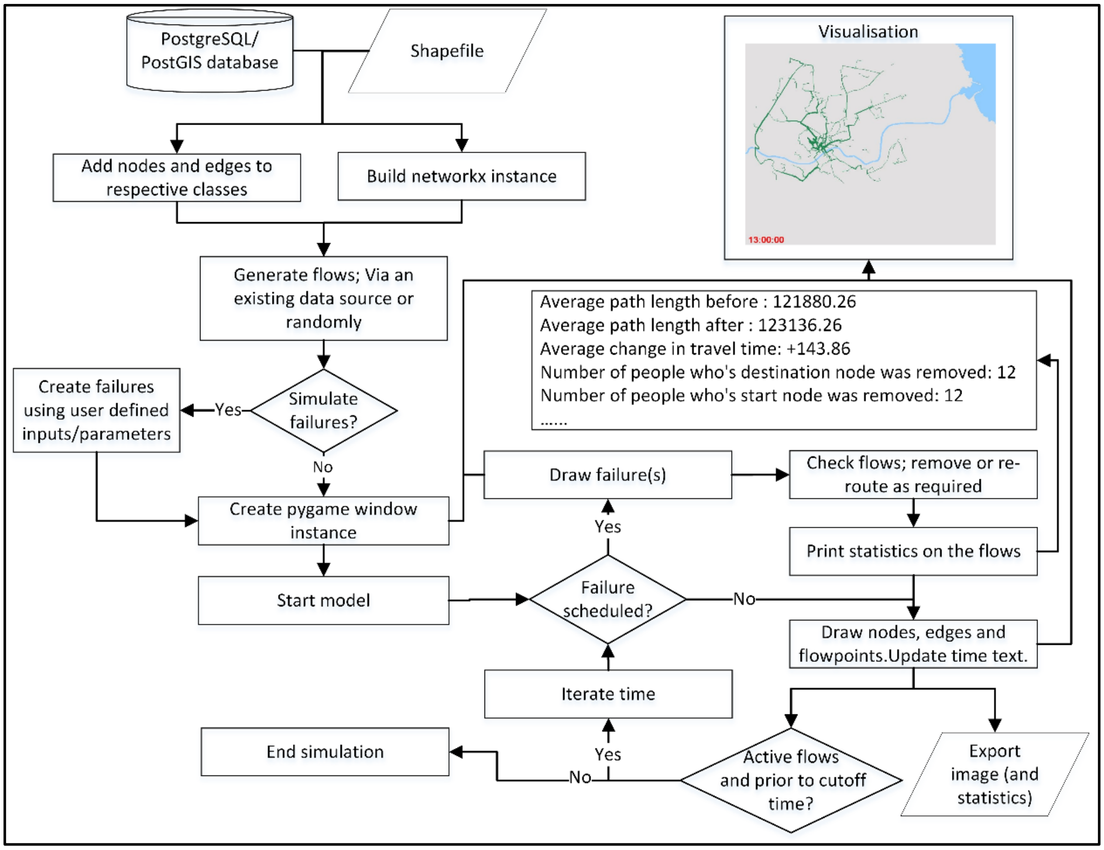

Figure 1: Flow diagram illustrating the visualization tool developed.

2.2 Network failure modelling

Spatial infrastructure networks are exposed to a wide range of events which can affect component performance, from natural hazards through to breakdowns and stress due to demand (Demšar *et al.*, 2008). The ability to model such failures has been integrated within our tool in the form of three failure models; namely, (i) targeted failures such as failures ranked by node degree (number of incident edges), (ii) failures due to stress on the network for instance failures on edges exceeding a certain flow limit and (iii) failures due to natural hazards such as floods (spatial footprints represented in shapefiles for example). These failure methods can be applied to both nodes and edges, with the perturbation of both being possible within a single simulation run. During a failure simulation run all active flows or movements are checked and if their shortest/least cost path intersects the failed node(s)/edge(s) an alternative shortest/least cost path is re-calculated if possible and the affected flows assigned to the new route. At the same time any changes to the network structure are also recorded along with corresponding failure metrics (Figure 1).

2.3 Network visualisation

Visualisation of the network and its evolution of flows as a result of the failure model applied is undertaken using PyGame, an open source software package designed for developing games in OpenGL. Initially, static imagery is added to the PyGame canvas to provide geographical context and initial configuration of the network rendered from the network class. Once the simulation commences, the network are re-rendered according to the user specified simulation time step (e.g., every 30 seconds). Within the visualisation engine the dynamics of the changing network flows can be represented by either adjusting the size/thickness or colouring of edges/nodes to depict the number of flows across each network primitive at a given time period i.e. the last 10 minutes. The actual flows themselves can also be visualised, with a point plotted at each epoch.

3 Tyne and Wear traffic analysis

The developed tool was used to analyse the Tyne and Wear road network during the day of the Tyne and Wear derby (Newcastle United vs Sunderland). Flows were extracted from recorded geotagged tweets on this day; when a single Twitter user tweeted more than once throughout the day from different locations these were used to form a route that was mapped to the road network to create a network flow. From the twitter data 1337 flows were created and applied to the road network. An initial simulation was run to investigate hourly flows across the network (Figure), that showed flows increased in the city centre before dying down as the games kicks off at 12:45 and then increased again around 14:30 as the fans begin to leave the football ground. Visible pinch-points occurred in traffic routes over the River Tyne, so a failure analysis at these locations was undertaken to analyse the effect of closing these roads. The failures were introduced at 11:00. Figure 3 shows the evolution of the routes post-failure showing previously low flow stretches of road experiencing dramatic flow increases in order to accommodate the lack of accessibility due to the failure of the principles bridges across the river Tyne.

4. Conclusion

Visualising the spatial behaviour geospatial infrastructure networks has the potential to offer new insights into the dynamics of the networks which we rely upon for our quality of life and economic prosperity. The tool we have developed allows us to gain a better understanding of network behaviour when exposed to perturbations, enabling changes in flows across system to be assessed spatially over time, and thus allow spatially those parts of the system that may require adaption to be recognised. Future work will extend the tool to incorporate directly sensor flow data and to integrate this tool into a real time decision theatre environment.

Figure 2: The loading of flows over the road network from 10:00 to 16:00.

Figure 3: Comparing the traffic loads if two main road arteries were to be closed during the same period.

5. Biographies

Neil Harris is a researcher in Geomatics at Newcastle University. Whose research centres around the collection, management , analysis and visualisation of geospatial sensor and social media data.

Mr Craig Robson is currently studying for a Ph.D. in spatial infrastructure network modelling at Newcastle University.

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