Multi-Agent Simulation of Drivers Reactions to Unexpected Incidents on Urban Road Networks

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ABSTRACT: The wide-scale impact of unexpected road closures is difficult to predict across entire urban road networks. Drivers seek new paths around the blockages, leading to the emergence of congested areas in unforeseen parts of the network. In order to predict and mitigate for these circumstances the full variation in driver behaviour must be incorporated into any simulation. This paper presents initial work on a multi-agent simulation whereby driver agents replan their route, in response to a road closure, based on their own personal knowledge of the network. A real-world scenario is presented that demonstrates resulting global responses to road closures.

KEYWORDS: Urban modelling; Road congestion; Agent-based Simulation; Spatial cognition; Urban complexity.

1. Introduction

Unanticipated incidents and blockages in the road network represent a significant challenge for traffic managers and a frustration for users. Such events, usually resulting from an accident or faulty infrastructure, often necessitate lane or road closures, significantly reducing network capacity. The impact of enforced closures can be considerable, particularly where demand for road space is already high, when tailbacks can grow rapidly and drivers divert in attempts to reduce their own delay. It has been suggested that such incidents are a greater contributor to congestion than high demand alone, with numerous studies identifying its contribution towards between 50% and 55% of all congestion (Barton 2004, FWHA 2005). A reduction in this so-called non-recurrent congestion is unlikely to be seen in the near future as greater numbers move into urban areas, with up to 70% of the world's population predicted to live in cities by 2050 (United Nations 2009).

Despite the clearly detrimental influence of these events, there remains a generally poor understanding of how to model and predict their impact across entire urban road networks. In part this may be attributed to the research focus within the transport community, where there has been a greater emphasis placed on predicting the movement of the urban population on a 'normal', day-to-day basis. While such models are highly capable of predicting the location of congestion hotspots during peak hours, they rely on simple assumptions and homogeneities regarding the behaviour of drivers (Goodwin 1997, Bonsall 2003, Andriotti and Klugl 2006). Whereas such assumptions have relevance within the normal bounds of the system – commuters generally stick with a tried-and-tested route – where uncertainty exists the same models of behaviour become unrealistic. Where predictions of traffic patterns are derived from an accumulation of such behaviours, the results can be widely inaccurate.

Within times of uncertainty then, simulating the full extent of driver behaviour becomes all the more important. The spatio-temporal traffic patterns in response to such events become a product of driver decision making. Individuals are forced to reconsider their planned route to their destination based on their new environmental constraints, while also anticipating the actions of others. In large cities, this process occurs on a scale of thousands of individuals leading to a mass displacement and relocation of vehicles across the road network. Whereas the road network would otherwise, within its design capacity, remain largely able to deal with the small fluctuations in traffic flow, such changes lead to the flow decreases and delays that characterise non-recurrent congestion. As more and more vehicles adjust their routes in response to the closure and subsequent delay, this congestion may be viewed as moving across the network in space and time.

This paper will present the on-going work towards the simulation of non-recurrent congestion resulting from driver response to unexpected incidents on urban road networks. The following section will detail the methodological approaches underpinning this work, both theoretically and technically. In the third section there will be presentation of results yielded from early simulation work, relating to a real-world scenario. Finally, there will be discussion of future work to be carried out on this project and concluding remarks will be offered.

2. Methodology

As described above, the link between the driver behaviour and the movement of non-recurrent congestion is indelible. It is therefore important that the simulation of such a phenomenon be built on a strong conceptual model of driver behaviour. In modelling the individualistic behaviour of many individuals, one aims to develop a broader picture of mass movement. The following subsection describes, in brief, some of the pertinent aspects of driver behaviour being addressed in this model, before details are given on the precise nature of the agent-based model developed here.

2.1 Spatial Knowledge and Driver Behaviour

Changes in driver behaviour in response to new conditions are governed by each individual's perception of their environment. In this case, this foundational understanding is a model of space and location (Golledge and Garling 2001). This knowledge is formed through experience and, to a certain extent, through the use of maps. With this knowledge an individual is able to navigate around a given environment. Such understanding can be modelled using the concept of the cognitive map. Introduced by Tolman (1948), and expanded upon and formalised by several others (Lynch 1960, Downs & Stea 1973, Passini 1984), this is the theory that each individual possesses a personal representation of spatial understanding in their brain. Such understandings are partial and hierarchical, with stronger knowledge of certain elements. Models of individual use of cognitive maps have been incorporated into a number of computational models for pedestrian movement (Kuipers 1978, Gopal et al. 1989, Chown et al. 1995).

In addition to the spatial knowledge held by the individual, a wide number of other factors are likely to have an impact upon the route by which a driver picks their route. Of particular note is routing heuristics – the decision and selection process by which individuals pick their route – a process more complex than simply picking the shortest route (Golledge and Garling 2001). In addition other influencing factors may include tendencies to avoid congestion, the influence of in-car guidance, willingness to pay a toll and the impact of the weather conditions.

2.2 Simulation Process

Capturing the macroscopic phenomena arising through the interactions of many individuals is a key property of Agent-based Modelling (ABM). ABM has been used across many disciplines to demonstrate the impact of individual decisions and choices on the nature of a system. Such examples include the individual behaviours of birds in flocks, ants in colonies and people in crowds – all entities are acting independently yet contribute to a larger body (Bonabeau 2002). There is great potential within ABM to replicate and predict system changes over space and time. In the case of this work, the decisions of individual driver agents contribute towards the formation of non-recurrent congestion in unforeseen places at certain times.

A simulation of this phenomenon was implemented using the Java-based Repast Symphony framework (2011). Utilising the GIS simulation tools provided in this toolkit, ArcGIS Shape files were used as a foundation for the model, providing input data regarding the road network, origins and destinations of the vehicle agents. The test area selected for this simulation was the whole of London, with a road network extracted from the Ordinance Survey Integrated Transport Network (ITN) dataset. Before each execution of the simulation the option is provided to enforce a road closure on a specific segment of the road network.

Driver agents are created at the imported origin points and assigned a random destination from those imported in the Shape files. The number of agents to be created at each point is specified within the data of the Shape file. On creation, agents are granted one of three profiles – either 'taxi driver', 'commuter' or 'tourist'. These definitions accord the level of spatial knowledge the agent will possess. The extent of knowledge that each profile is assigned is hierarchical in nature. 'Taxi driver' agents hold knowledge of all roads in the network, with 'commuters' knowing fewer and 'tourists' having knowledge of only the key roads. Further heterogeneity is introduced into the population by granting some drivers advanced road closure information and others the ability to travel through the Congestion Charge Zone.

Using their distinct spatial knowledge foundation, agents then individually calculate their route from origin to destination. Accordingly, they are only able to select routes that they have knowledge of, in other words, that exist within their cognitive map. At this stage, this involves simply the shortest path between the two points, although as specified above, real world planning has been shown to be more complex than this. Planning is further influenced by whether the agent wishes to travel in the Congestion Charge Zone and whether they have advanced traffic information.

Agents then proceed in attempting to complete their chosen route between origin and destination. During their journey agents travel at a random speed selected from a Poisson distribution around 30mph, however, should they meet another car in front of them travelling at the same speed they must adjust their speed accordingly. Likewise, should two agents reach a junction at the same time they must negotiate as to which may proceed and which must wait according to certain rules. Otherwise a vehicle will proceed until they meet an unexpected road closure, at which point they must replan their route from that point, again based on their underlying route knowledge. Vehicles which hold advanced traffic information will have already taken such closures into account whilst planning their original route.

The simulation is able to export periodic data regarding the movement and speed of vehicles around the network, enabling the comparison of behaviour in normal and irregular environments. The next section will describe one test carried out to demonstrate the impact of population-wide response to road closures, something that allows us to draw assumptions about the spread of non-recurrent congestion in response to these events.

3. Preliminary Test and Results

The following example demonstrates succinctly the results that may be generated from this current simulation. At this stage, the results demonstrate the changes in global traffic patterns in response to unexpected events, but not yet the extent to how and where congestion may form at certain locations.

3.1 Closure of Blackwall Tunnel

In this test, 900 vehicle agents were created at six origin points in east London, with a destination point at Sun-In-The-Sands roundabout in south London. The shortest path between the two points is through the Blackwall Tunnel, underneath the River Thames. The simulation was run as described above and data relating to route-choice exported.

Figure 2 shows a map of the vehicle counts on each road segment where no closure is seen, following what would be expected (Blackwall tunnel is indicated with the white arrow). Figure 3 demonstrates how the traffic spreads in response to the closure. In this latter case, many head to start of the tunnel then divert on finding it closed, however there is also redistribution onto other roads where agents have advanced traffic information. The routes chosen in response demonstrate where some may know shorter paths others must take a longer diversion.

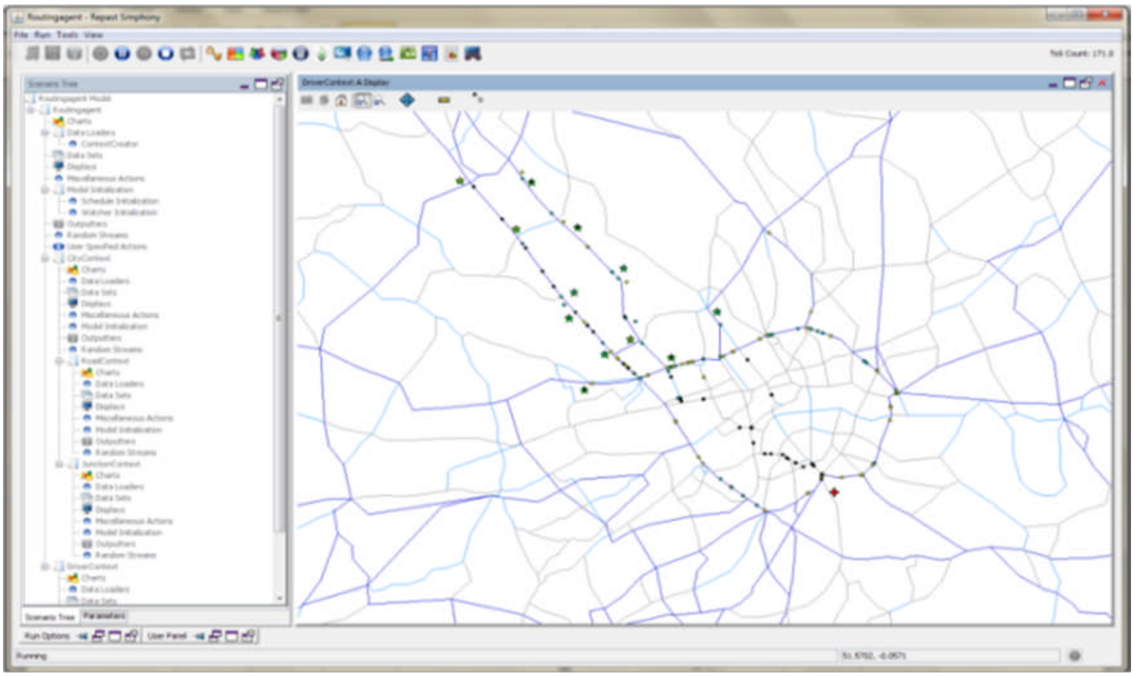

Figure 1: Screen capture from simulation interface

Figure 2: Movement through Blackwall Tunnel (indicated) with no closure

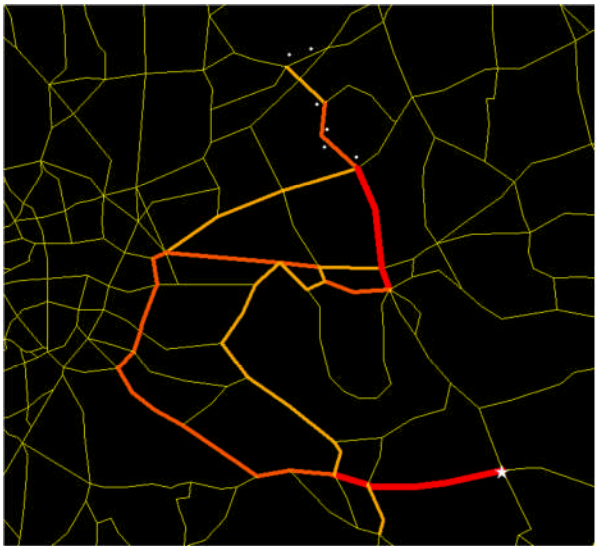

Figure 3: Movement in response to closure of Blackwall Tunnel

The simulation also records average journey times for each type of agent, providing an indication of how much the diversion slows journeys. These do not take account of congestion at the closure points but do provide an indication of how those with greater knowledge are able to identify quicker routes around closures. From the distribution of flows one may be able to make predictions about the location of where congestion might develop. Chart 1 displays these differences, whereby clearly ‘taxi drivers’ are able to identify shorter routes to the destination than other types of driver:

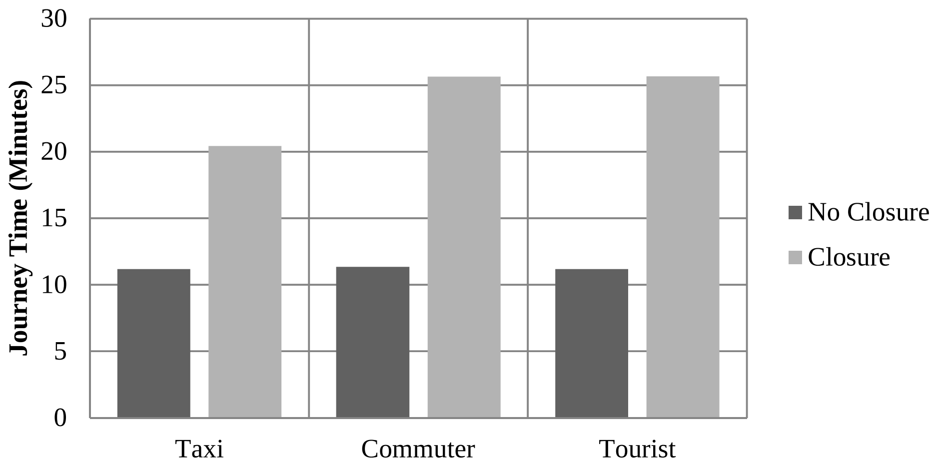

Chart 1: Average journey times by profile prior to and after Blackwall Tunnel closure

4. Conclusions and Future Work

This paper has described work carried out towards developing a simple model of driver behaviour in response to closures in the urban road network. The agent-based simulation presented has shown how variation in spatial knowledge across a population is highly influential upon the movement of individuals through urban road networks. Driver spatial knowledge becomes of greater importance in situations where an individual has to make a change to their customary route, such as where a road is blocked. In these cases, this mass reselection of routes may result in demand exceeding road supply at certain locations, leading to the formation of non-recurrent congestion. Therefore only by understanding the behaviour of drivers at the individual level are we able to gain an understanding of where and when this form of congestion may arise. With such a predictive simulation, it may be possible for transport managers to better manage and mitigate for such incidents.

This paper has presented the early steps towards achieving this goal. Although the simulation incorporates somewhat simple abstractions of driver behaviour, and thus cannot yet be compared to real traffic flows, there is clear potential and direction for development of this simulation. Future work will concentrate upon improving the conceptual behavioural model and incorporating this within the agent-based environment.

There are two key stages to this future work; firstly, introducing great complexity into the process by which agents are granted spatial knowledge, and secondly, using more realistic models of route-choice. On this first point, models of route knowledge will be sought from individuals through interviews and questionnaire. These will help inform the process of how spatial knowledge is assigned. Secondly, in terms of routing heuristics, datasets will be sought that demonstrate the movement of individuals in both normal and abnormal conditions. The similarity of these movements to existing theories (both quantitative and qualitative) around routing may be derived and judgement made about the most suitable routing heuristic to employ in the simulation. The ultimate aim of this work is to provide a platform for the analysis and management of the network-wide changes in traffic flow in response to irregular environments. By incorporating these innovative modelling aspects, it will be possible to gain an understanding of the spatio-temporal changes right across the network.

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Biography

Ed Manley began his Engineering Doctorate in Urban Sustainability and Resilience at UCL in August 2009. He holds an undergraduate degree in Computing, with a Masters in GeoInformatics. His research interests include complexity, agent-based simulation and spatial cognition. Ed's research is kindly supported by the EPSRC and Transport for London.

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