Intelligent mobility applications for the UK strategic road network: data-driven classification, modelling and prediction of motorway congestion

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Background

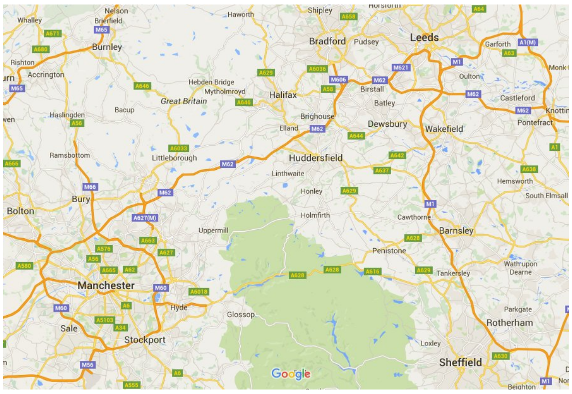

Figure 1: A section of the UK strategic road network in northern England.

Improvements in the capacity and reliability of transport systems, including road transport, have been shown to impact directly on economic performance as well as improving the quality of life for citizens. In the UK and other developed economies, there is limited scope to increase the capacity of strategic road networks by building more motorways. Current transportation policy and research is therefore very heavily focussed on intelligent mobility rather than on construction of new infrastructure. In the road transport context, intelligent mobility is largely about using existing infrastructure more efficiently through the use of real-time data [1]. The UK is considered world-leading in its ability to collect and process real-time data from its strategic road network. The UK has been among the first countries to deploy innovative large scale systems which use this data, such as the smart motorways scheme piloted on the M42 in Birmingham and now scheduled for wider deployment nationally. Highways England collects data about traffic flows, speed and travel times on England's road network. This is done using sensors on the roads and in vehicles which form part of the National Transport Information Service (NTIS) which is operated by Thales UK in collaboration with other partners. This project is about looking at ways to better use data provided by NTIS to understand and predict traffic congestion.

Research challenges

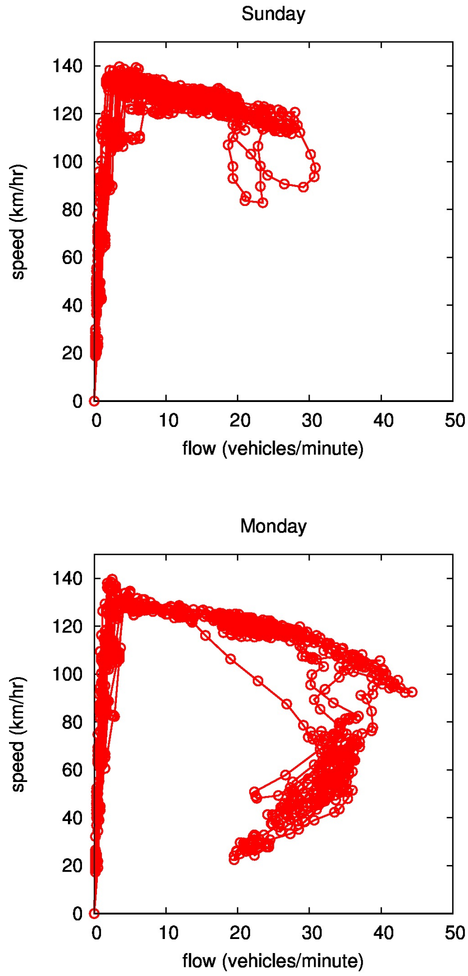

Figure 2: Comparison of scatter plots of speed against flow rate obtained from a single induction loop on the M62 motorway on a Sunday and a Monday.

UK motorways incorporate thousands of induction loops at different sites throughout the network which report speed and flow (number of vehicles crossing per minute) to a centralised system. This data is made available through NTIS. Some sample data from a single induction loop is visualised in Fig. 2 as scatter plots of speed versus flow. Such data will be used as the basis for this project.

There are three strands to this project with the students afforded the freedom to decide the emphasis:

- Definition of congestion events from loop data and construction and validation of a predictive model for the time for a congestion event to clear. This will include quantification of the forecast skill of different models to allow fair comparison. It is expected that it would be reasonable to start from a simple regression model similar to that developed by Wilson and co-workers for traffic accidents [4].
- The Monday data in Fig. 2 clearly shows a transition between a high density-high speed regime and a high density-low speed (congested) regime which is absent in the Sunday data. This part of the project will use machine learning to search for the signatures of such transitions across all the sensors on the UK motorway network. The objective is to classify the structure of such transitions - is there one type or many? Can one identify informative summary statistics which characterise the transition in a low-dimensional space? Can such a low-dimensional description, if it exists, be used as the basis of a predictive model?
- Continuum models of traffic flow based on "fluid dynamics" style nonlinear partial differential equations range from the foundational conceptual model of Lighthill and Whitham [3] to large scale computational models incorporating the geometry of the real motorway networks [2]. The availability of real-time data is a potential game-changer in the validation and deployment of such models. This part of the project will constitute an open-ended consideration of the merits and shortcomings of continuum models of traffic flow based on nonlinear partial differential equations when the availability of observational data is taken into account. This could involve quantification of the predictive power of such models for some well-defined test cases and assessing the trade-offs between realism, computational requirements, predictive power and number of parameters which require estimation. One avenue with significant potential for novel advances is to investigate whether the predictive power of fluid models of traffic flow can be improved by running a data assimilation algorithm in parallel with a numerical PDE solver.

Pre-requisites

This project is heavily data-driven and students will be required to work hard to extract, clean and analyse data streams provided by NTIS. The students will be expected to know or be willing to learn standard statistical methods for making predictions such as multivariate regression and design of statistically defensible procedures for assessing the accuracy of predictions, machine learning techniques for unsupervised classification such as hierarchical clustering, some basic knowledge of nonlinear PDEs, the method of characteristics and their numerical methods like the finite element method, entry-level data assimilation methods such as the linear Kalman filter.

Additional considerations

This Research Study Group project will lead into a follow on individual MSc research project. If the project goes well and succeeds in identifying potentially valuable avenues for future research, it is expected that it will lead to a PhD project co-sponsored and co-supervised by Thales UK. One of the most striking features of the data in Fig. 2 is that the Monday scatterplot shows clear evidence of bistability - the co-existence of a high-speed and low-speed regime at the same flow rate. This suggests that the transition to congestion cannot be easily modelled as a continuous phase transition. Such bistability has recently been shown to be crucial to understanding the transition to turbulence in pipe flows [5] explaining a long-standing puzzle as to why the transition to turbulence cannot be modelled as a continous phase transition characterised by a critical Reynolds number. Exploring the analogy between these two models would be an interesting direction for a theoretically-minded PhD student.

References

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