Mathematics for traffic engineering

by David Shteinman

Engineers responsible for road traffic engineering should consider the use of industrial mathematics to solve complex problems, particularly where conventional software programs are not available or do not work.

At the Australian Centre for Commercial Mathematics (ACCM) we recently worked with the NSW Roads and Traffic Authority, now Road and Maritime Services (RMS), to develop a statistical framework to guide traffic simulation studies. Due to the huge expense of designing and building new road infrastructure or testing alternative traffic scenarios, all design changes are first assessed in micro-simulation, the simulation of individual vehicles in a traffic system. In collaboration with RMS, ACCM identified a need for rigorous statistical analysis of the outputs of micro-simulation. The main objective was to increase confidence in the results of simulation models.

In collaboration with RMS' Network Performance Development Group, ACCM designed and built a rigorous statistical framework to inform the design stage and analyse the outputs of traffic micro-simulations. The resulting framework now gives transport modellers the ability to perform statistically rigorous and efficient analysis of option testing and scenario comparisons, quantify confidence in reported outputs, quantify and correct bias due to boundary congestion effects, use graphical tolls to assist interpretation of results and diagnose model problems before finalising results.

At the conclusion of the project, the ACCM converted the detailed statistical methods into the user-friendly *Statistical toolkit for model confidence and stability.* It is a guide to assess micro-simulation model stability. The toolkit is now part of RMS' *2012 Traffic modelling guidelines.*

The guidelines offer a range of statistical tools tailored for use in transport modelling and simulation, including power analysis. Power analysis illustrates how the larger the sample size, the smaller the difference detectable between the two scenarios. Power curves (see breakout below) are the graphical display of the outputs of a power analysis. The curves inform the modeller exactly how many runs are needed to detect a certain difference given variability in the samples, or (conversely) what difference can be reliably detected with a given number of simulation runs.

Road authorities frequently spend large sums of capital on changes to network infrastructure to improve flows at bottlenecks. However, due to the inherent "noise" in traffic data and the presence of known and unknown confounding variables within the traffic environment, it is very difficult to quantify the degree of improvement that can be attributed to the infrastructure change itself. These confounding variables mean that it is difficult to be confident that an observed effect following a traffic system intervention is due to the intervention itself or due to a coincidental change in the traffic environment as a whole.

Working with VicRoads' Network Operations Group, ACCM approached this problem by adapting a method used in environmental science known as before and after control impacts (BACI) that is specifically designed to detect and quantify intervention effects within complex systems. It is the first time this method has been applied to a transport engineering problem in Australia.

The BACI method involves choosing a control site or sites where no intervention is applied and taking measurements before and after the intervention at this control site *in addition* to taking measurements before and after the intervention at the intervention site. The approach was tested at VicRoads on a post-implementation review of a change to rail level crossing timing. The method specifically separates a control site from the "intervention site" where the change occurred. It then attributes a degree of improvement in factors such as in travel time and delays to the intervention itself. Application of BACI methodology in the VicRoads study succeeded in showing that while the change to the level crossing timings did not change the average delays, it did make a significant reduction in the occurrence of very long delays as shown in the tails of the data.

The method can be applied to any intervention effects in a complex system. It is now being tested in other traffic improvement programs as part of the auditing/post-implementation review process.

Other problems in transport and traffic modelling tackled by the ACCM using advanced mathematics and statistics include: arterial travel time estimation, improving travel time estimation on freeways, designing and implementing a meso-scale simular to test alternative intersection control regimes, and developing a system for existing intersection controllers to perform cordon control or "gating" on an arterial network. ■

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Power curves

The RMS' *2012 Traffic modelling guidelines* includes a range of statistical tools, including power analysis which produces power curves. Each curve depicts the results of several runs of a simulation. Each simulation produces an aggregate travel time of a number of vehicles in a scenario. Changing road infrastructure changes the aggregate travel time. When comparing the power curves of two scenarios, the more runs performed the more accurate the calculated difference. The power curves to the right show a case of using 50 simulation runs versus 100 simulation runs. For 50 runs, the detected difference is 234h, while for 100 runs the detected difference is 164h. ■