DEVELOPMENT OF A STATISTICAL FRAMEWORK TO GUIDE TRAFFIC SIMULATION STUDIES

Christian Chong-White
Traffic Algorithm Development Manager, Roads and Traffic Authority of NSW
RTA Traffic Management, Australian Technology Park, Eveleigh, NSW 1430 Australia
Christian_CHONG-WHITE@rta.nsw.gov.au

David Shteinman
Industry Projects Manager, Australian Research Council, Centre of Excellence for Mathematics & Statistics of Complex Systems
School of Mathematics & Statistics, University of New South Wales, Sydney, NSW 2052 Australia
davids@complex.org.au

Gary Millar
Software Support & Development Manager, Azalient (Australia) Pty Ltd
Suite 145 National Innovation Centre, 4 Cornwallis Street, Eveleigh NSW 2015 Australia
gary@azalient.com

Fraser Johnson
Manager, Network Performance Development, Roads and Traffic Authority of NSW
RTA Traffic Management, Australian Technology Park, Eveleigh, NSW 1430 Australia
Fraser_JOHNSON@rta.nsw.gov.au

ABSTRACT

We present the results of a collaborative RTA-MASCOS research project that is working to provide (1) a methodological framework for analyzing simulation outputs, and (2) a framework to inform the design stage of a simulation study. The project aims to improve the statistical rigor and defensibility of study results. We present a high-level update of the project results that indicate the contribution this project will provide to the design, planning and evaluation of traffic simulation studies. We adapt the exploratory data analysis techniques (EDA), traditionally used in industrial quality control, to the analysis and design of traffic micro-simulations. This includes graphing the output distributions to expose the salient features, screening the data for errors, missing values and most importantly, outliers. Outlier analysis is used as a diagnostic tool to distinguish between model errors and genuine rare events. The salient features of the data revealed by EDA used to build a functional relationship between changes in the complexity of simulated network features, the range of confidence intervals, precision and simulation run size.

INTRODUCTION

Traffic simulation is an analytical tool used to evaluate and compare simulated-traffic management policy outcomes; the criticality of this analysis task requires that such studies provide robust and defensible information.

Experienced simulation practitioners state that typically most resources in a simulation study are devoted to model building and validation. Comparatively fewer resources are devoted to analyzing the results in a valid statistical framework [10]. This results in simulations that may not be statistically valid and "as a result, these estimates (of the simulation) could, in a particular simulation run, differ greatly from the corresponding true characteristics for the model. The net effect is, of course, that there could be a significant probability of making erroneous inferences about the system under study" [10, p. 67].

The Roads and Traffic Authority of NSW, Australia (RTA) and the Centre of Excellence for Mathematics and Statistics of Complex Systems (MASCOS) [1] formed a collaborative research project to work towards developing: (1) a methodological framework for analyzing simulation outputs, and (2) a framework to inform the design stage of a simulation study.

We present a high-level update of this project, which is currently at an advanced stage of progress at the time of writing this paper.

The originating stimulus for the study was the need for defensible simulation modeling of the Sydney Coordinated Adaptive Traffic Control System (SCATS) [6] when used with the SCATSIM [5] platform (e.g. [7]), and other associated advanced traffic control (ATC) systems (e.g. [8], [9]). This type of modeling often requires investigation of traffic performance changes of small magnitude at a localized level; this phenomenon drives the particular need for a robust and defensible statistical analysis approach. However, the project aims for a general framework that can be applied to any traffic simulation, irrespective whether the focus of the study involves the mentioned systems or not.

THE PROBLEM

Micro-simulations are often used to create and compare a set of simulated scenarios. This set of scenarios consists of a base-case scenario, and at least one alternative 'what-if' scenario; we refer to this facility as the ‘comparative-scenario modeling problem’.

To make this modeling statistically valid, and therefore defensible, it is necessary to determine whether the difference in a performance measure between two scenarios is either statistically significant (the difference is due to a real difference between the scenarios) or just the result of randomness. The difference will be determined within certain confidence limits.

However, existing traffic micro-simulation software packages often do not provide sufficient support for comprehensive statistical analysis on outputs; this has two implications:

1. For a single scenario being simulated, statistical features of the data are not fully considered. This includes confidence intervals for measured outputs (e.g. total vehicle hours), of outliers, effect of number of runs on precision of results etc,
2. For pair-wise comparisons, there are no confidence intervals on the differences between the two scenarios nor any ways of determining if the differences are statistically significant.

A statistical analysis is also required in the planning stage of a study, e.g. to determine the minimum number of simulation runs to give a required confidence interval on the results such as mean vehicle hours travelled (VHT), average speed etc. Currently, planning a study is difficult because there is little quantified assessment of the cost of modeling as a function of the size, complexity, features etc. of the network being simulated.

THE SOLUTION

We present the three stage process of i) Formal problem definition, ii) Exploratory data analysis on a wide range of micro-simulation models, and iii) Development of a statistically based set of guidelines or “framework” that relates simulated network features to expected confidence intervals and run size.

Building a framework to guide micro-simulations first requires exploratory data analysis (EDA) on a wide range of typical model outputs to establish the salient features of key input/output relationships. This includes determination of confidence intervals for key outputs using a fixed sample size procedure, assessing coverage of the interval for differing distributions of output, interpretation of the shape and features of distributions of outputs and measurement of departure from Normality. We review sequential procedures for obtaining a specified precision and confidence interval size. Statistical theory is interpreted for a wide range of types of networks model that give a representative sample of networks that are likely to be simulated (a total of 37 different models are tested). The full paper will give results of the EDA on the 37 models.

We adapt the exploratory data analysis techniques traditionally used in industrial quality control to the analysis and design of traffic micro-simulations. This includes graphing the output distributions to expose the salient features, screening the data for errors, missing values and most importantly, outliers. Outlier analysis is used as a diagnostic tool to test for model errors and genuine rare events.

Descriptive Statistics of a wide range of models are displayed: shape of output distributions to help identify salient features, Confidence intervals on key measure such as VHT, VKT, for increasing number of runs: N=10, 20,50,100 and determination of the number of runs required for a specified precision. The effect of congestion on outputs is also determined.

The salient features of the data revealed by EDA are interpreted in the final stage of the framework development. Here we present the results in a Matrix of network features with respect to confidence interval size, precision, and required run size as a function of sensitivity to changes in the following input factors: *number of zones, shape of distribution of output measures, number of links per node, size of network, topographical shape of network, total number of vehicle trips, time duration of simulation with respect to duration of congestion periods and recovery time, boundary effects of congestion (unreleased vehicles or incomplete trips)..*

A by-product from the process of developing the 'Matrix" framework will be to provide support for the initial specifying, planning and/or costing of traffic simulation studies.

Finally, the issue of *statistical efficiency* of a simulation is investigated. The aim is to obtain a required precision with less simulation runs or higher precision with the same number of runs under normal methods. We achieve this by reducing the standard deviation in the output measure of interest by using *Variance Reduction Techniques* (VRT) such as the "Common random number" method. This is motivated by the generally high cost of running complex simulation models.

RELATED WORK

The RTA has developed a sophisticated manual [4] to guide their projects that use the micro simulation application, Paramics [2]. The framework developed in the project aims to contribute to the guidance offered in this manual.

CONCLUSION

We introduced the RTA-MASCOS research project that is working to provide (1) a methodological framework for analyzing simulation outputs, and (2) a framework to inform the design stage of a simulation study. The project aims to improve the statistical rigor and defensibility of study results. We presented a high-level update of the project results that indicated the contribution this project will provide to the design, planning and evaluation of traffic simulation studies.

REFERENCES

[1] MASCOS, ARC Centre of Excellence for Mathematics and Statistics of Complex Systems, 2007, Available at http://www.complex.org.au

[2] Quadstone Paramics Ltd., "Modeller", *Quadstone Paramics* (traffic microsimulation software), Version 5.2.2, June 2006, Available at http://www.paramics-online.com/product_modeller.php.

[3] Roads and Traffic Authority NSW, "Home", *Website*, 21 January 2010, Available at http://www.rta.nsw.gov.au/

[4] Roads and Traffic Authority NSW, "Paramics microsimulation modelling - RTA manual", *RTA manual*, Version 1.0, Roads and Traffic Authority NSW, Sydney Australia, 10 May 2009, Available at http://www.rta.nsw.gov.au/doingbusinesswithus/downloads/technicalmanuals/paramicsmanual_i.pdf.

[5] Roads and Traffic Authority NSW, "Simulation software – SCATSIM", *SCATS product family options (webpage)*, Roads and Traffic Authority NSW, Sydney Australia, 10 January 2010, Available at http://www.scats.com.au/product_family_options.html.

[6] Roads and Traffic Authority NSW, "SCATS", *SCATS (webpage)*, Roads and Traffic Authority NSW, Sydney Australia, 10 January 2010, Available at http://www.scats.com.au/product_base_packg_compnts.html

[7] Chong-White, C, Millar, G and Johnson, F, "Introduction to modeling experimental design when operating scats within simulation", 17th *ITS World Congress, Busan 2010*, pending approval available at http://www.itsworldcongress.kr/.

[8] Geers, G, Tyler, P, Chong-White, C and Johnson, F, "Roundabout metering: simulation and reality", 17th *ITS World Congress, Busan 2010*, Korea, Busan, pending approval Available at http://www.itsworldcongress.kr/.

[9] Chong-White, C, Hengst B, Quail D, Geers G and Goeldner G, "NICTA-RTA partnership for traffic control innovation", *15th World Congress on ITS*, November 2008, New York City, New York

[10] Law A “Statistical Analysis of Simulation Output data: The Practical State of the Art" A M Law, , *Proceedings of the 2004 Winter Simulation Conference*

[11] "Guidelines for applying Traffic Micro-simulation Modeling Software" *California Dept of Transportation*

[12] Simulation Modeling and Analysis, *A M Law, McGraw Hill, 2007*

[13] "Statistical Analysis of Simulation Output data" *Operations Research* vol 31, No.6, pp 983-1029

[14] "Statistical analysis of Simulation Output" W D Kelton, , *Proceedings of the 1997 Winter Simulation Conference*

[15] "Statistical Analysis of Simulation Output data: The Practical State of the Art" A M Law, *, Proceedings of the 2004 Winter Simulation Conference*

[16] "Review of Advanced Methods for Simulation Output Analysis" C Alexopoulos*, Proceedings of the 2005 Winter Simulation Conference*

[17] "On the Requirements of Simulation Output Analysis Software" Proceedings of ESS '99 the European Simulation Symposium,

[18] *"*Exploratory Data Analysis*" C Chatfield, European Journal of Operational Research, vol.23, (1986), 5-13*

[19] *"*Avoiding Statistical Pitfalls*" C Chatfield, Statistical Science, Vol. 6, No. 3, 240-268*

[20] "Use of Micro simulation to model day –to-day- variability of Intersection performance*" Z Abdy, B Hellinga, Transportation Research Record, No 2088, pp. 18-25*

[21] "Traffic Flow Theory A State of the Art Report" *Transportation Resrach Board, 2001*

[22] *"Design and Analysis of Simulation Experiments" J P C Kleijnen,*

[23] "Validation And Statistical Analysis Procedures Under The Common Random Number Correlation-Induction Strategy For Multi-population Experiments" *S Joshi, J Tew, European Journal of Operational Research vol.85 (1995), 205-220*

[24] *"Simulation Approaches in Transportation Analysis Recent Advances * Challenges" Ed. R Kkitamura, M Kuwahara, Springer Science, 2005*