Authors Padma Seetharaman, David Watling, Chandra Balijepalli

Title **Markovian framework to assess strategy choice in a transit network service influenced by endogenous and exogenous reliability factors**

Track General Papers

Director Mark Wardman
Mark Wardman

Abstract

Achieving sustainable transport through increasing transit patronage is the current focus of several governing bodies. Reliability has been found to be one of the key characteristics whose improvement could result in an increase in patronage of transit services (Balcombe et al. 2004). The reliability of a transit service may be influenced by both *endogenous factors* such as variations in: passenger demand and choice of services and *exogenous factors*, such as breakdowns, signal failures, weather conditions and special events (Kimpel, 2000).

On the other hand, there are several factors that may mitigate such impacts. Firstly, if operators understand the most important causes of unreliability, they may take measures to reduce their occurrence, e.g. improved vehicle maintenance to reduce breakdowns. Secondly, travellers repeatedly using such a system may adjust their choice of service, possibly on a day-by-day basis, in response to their experience. Thirdly, travellers may adopt risk-averse strategies, pre-trip, which minimise not just the expected trip time, but also consider its variance. Fourthly, prior to and during a particular trip travellers may have access to real-time information which allows them to adjust their travel choices in response to prevailing conditions.

In the current study we model these aspects of a variable transit network as a stochastic process. We develop the classical assumptions of frequency-based transit assignment (Spiess & Florian, 1989), however instead aim to produce a day-to-day varying probability distribution of flows. This modelling approach extends that of Teklu (2008) which considered only the endogenous sources of variation, to also include exogenous factors that affect unreliability. The model provides an internally *consistent* representation of the interactions between the various unreliable components, specifically: (i) the impact of both endogenous and exogenous causes of reliability on the dynamic strategy choices of passengers; (ii) the modelling of failure to board services due to such unreliable factors; and (iii) the various mitigating factors described above, including traveler learning processes, risk-neutral as well as risk-averse passengers, and access to real-time information.

We provide a mathematical specification of the model as a discrete time system, and show that it (in the case without real-time information) it satisfies sufficient conditions for regularity and ergodicity of the stochastic process; importantly, this shows that a single stationary distribution exists, and that an unbiased estimate of it can be obtained from a single Monte Carlo realization of the process. The case of real-time information is known to be more complex, since it violates the typical Markovian assumptions adopted (the costs experienced by passengers earlier within a day *t* may affect the strategy choice of passengers travelling later on the same day *t*). We address this problem by

reformulating the model as a continuous-time and event-driven process, thus establishing a continuous-time version of the Markov assumption.

The study then provides the results from various simulation experimental setups which follow the Markov Chain Monte Carlo (MCMC) framework, in order to explore the sensitivity of the day-to-day stationary distribution of flows to various input factors, such as the distribution of vehicle headways, growth in passenger demand, and service disruption probabilities Furthermore, two scenarios are evaluated to explore the influence of Advanced Traveller Information Systems (ATIS) on strategy choices and experiences during a disruption. Scenario 1 consists of random reductions in the frequency of the transit service along specific lines, (to mimic vehicle breakdowns. Scenario 2 consists of a disruption mimicking signal failures similar to that which may occur on the London Underground network, which results in decaying delays along the inter-arrival times of the transit services.

In conclusion, our method addresses several challenging issues in the modelling of unreliable transit services. Strict capacity constraints have proven especially daunting in the past, due to the difficulty in adapting the ‘hyperpath’ approach, based on Bellman’s principle, without underestimating the waiting costs of passengers at a downstream stop and overestimating the waiting costs of passengers at an upstream stop, as a result of equating the cost experienced by the passengers on the optimal strategy at the upstream stop to the sum of the cost experienced by the passengers at the downstream stop to the destination and the costs experienced by the upstream stop passengers from the origin to the intermediate stop. The other approach of dealing with congestion by means ‘effective frequency’ function introduced by (De Cea and Fernández 1993) also fails to account for the priority of passengers boarding on the upstream stops over those of passengers boarding at the downstream stops. The MCMC model in the study alleviates the above problems by introducing a strict capacity constraint for each generated run of the transit service.

Furthermore, our framework of ‘mean-variance’ cost allows account to be made of risk averse passengers; this differs from the SUE formulation of Szeto et al. (2011) by our adoption of the stochastic process approach, which we believe provides a more internally consistent representation of all aspects of variability. The current framework also differs from Gentile et al. (2005) in that we are accounting for strict capacity constraints and from Cats et al. (2011) by assuming that passengers are aware of inherent stochasticity of the network and hence choose their strategy taking this stochasticity into account.

References

BALCOMBE, R., MACKETT, R., PAULLEY, N., PRESTON, J., SHIRES, J., TITHERIDGE, H., WARDMAN, M. & WHITE, P. 2004. The demand for public transport: a practical guide. http://discovery.ucl.ac.uk/1349/1/2004_42.pdf

CATS, O., KOUTSOPOULOS, H. N., BURGHOUT, W. & TOLEDO, T. 2011. Effect of Real-Time Transit Information on Dynamic Path Choice of Passengers. *Transportation Research Record: Journal of the Transportation Research Board,* 2217, 46-54.

CEPEDA, M., COMINETTI, R. & FLORIAN, M. 2006. A frequency-based assignment model for congested transit networks with strict capacity constraints: characterization and computation of equilibria. *Transportation Research Part B: Methodological,* 40, 437-459.

COMINETTI, R. & CORREA, J. 2001. Common-lines and passenger assignment in congested transit networks. *Transportation Science,* 35, 250-267.

DE CEA, J. & FERNÁNDEZ, E. 1993. Transit Assignment for Congested Public Transport Systems: An Equilibrium Model. *Transportation Science,* 27, 133-147.

GENTILE, G., NGUYEN, S. & PALLOTTINO, S. 2005. Route Choice on Transit Networks with Online Information at Stops. *Transportation Science,* 39, 289-297.

HALL, R. W. 1983. Travel outcome and performance: The effect of uncertainty on accessibility. *Transportation Research Part B: Methodological,* 17, 275-290.

KIRNPEL, T. J. 2000. Time Point-Level Analysis of Passenger Demand and Transit Service Reliability. https://www.pdx.edu/sites/www.pdx.edu.cus/files/DP00-5.pdf

NGUYEN, S. & PALLOTTINO, S. 1988. Equilibrium traffic assignment for large scale transit networks. *European Journal of Operational Research,* 37, 176-186.

SPIESS, H. & FLORIAN, M. 1989. Optimal strategies: A new assignment model for transit networks. *Transportation Research Part B: Methodological,* 23, 83-102.

SZETO, W. Y., SOLAYAPPAN, M. & JIANG, Y. 2011. Reliability-Based Transit Assignment for Congested Stochastic Transit Networks. *Computer-Aided Civil and Infrastructure Engineering,* 26, 311-326.

TEKLU, F. 2008. *A Markov Process Model for Capacity-constrained Transit Assignment*, PhD thesis, University of Leeds (Institute of Transport Studies).