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ROBUST PERFORMANCE OF TRANSPORTATION NETWORKS USING QUANTILE METRICS

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The state of the art in transport network modeling is founded on the estimation of travel demands between origins and destinations (O-D matrices) by various techniques. Assuming the estimate matches the true O-D matrix, the analysis culminates with a network assignment procedure that generates the volumes and costs associated with those volumes on the links and paths of the network. However, there are always variations from the truth in such estimates. In this study we develop new metrics for network assessment by taking explicit account of such demand variability and uncertainty. The metrics consist of the calculation of quantile network costs. This assessment methodology leads to improved decision-making in transport planning and operations and can be used to develop management and control strategies that result in more robust network performance.

The following results were obtained in this study:

1. Characterization of O-D demand variability from field data.
2. Development of p-quantile metrics for network performance.
3. Computational procedures to assess performance using p-quantile metrics.
4. Calculation of robust controls following accepted norms of behavior.

These results are applicable in transportation analysis practice. First, producers of transport modeling software (such as, EMME or TransCAD) can implement these techniques in the estimation of p-quantile costs and thus obtain more robust and realistic plans. Second, transportation system managers can develop and test robust strategies for traffic control along the lines demonstrated in this study.

Following is a more detailed description of the new methodological developments in this study:

A. <u>Origin-Destination (O-D) matrix generation for NBNM (Near-Bayes, Near-Minimax) and NBNQ (Near-Bayes, Near-Quantile).</u>

A parametric model of the possible OD matrices is developed for a given network using the transportation data base which represents the natural uncertainty and variability of OD demand. This involves survey data, link counts and planning information. For computational purposes, one of the challenges is to uniformly generate a set of possible OD matrices T(y) where y varies over a lower dimensional (lower than the dimension of the matrix) parameter set. A probability distribution may be defined on the parameter set. Two such distributions of interest are the uniform and the Gaussian.

In this study we consider the mathematical properties of the set of OD tables under general constraints which include equilibrium conditions. In particular, when we consider the set of OD matrices as a continuum, we show that the space of possible OD matrices governed by the constraints is not connected. This makes Monte Carlo OD table generation more challenging. We show how to generate OD tables for use in robust control strategies in this general situation. We analyze and estimate p-quantile control performance for representative-sized networks.

B. <u>Development of the quantile extension of the NBNM (Near-Bayes, Near-Minimax) principle termed the NBNQ (Near-Bayes, Near-Quantile) principle.</u>

For a fixed O-D matrix one can calculate the resulting network performance (for given demands and given controls) using accepted equilibration procedures such as Frank-Wolfe or the like. Hence for fixed network controls, for each OD matrix T(y) where y is in the parameter set, a cost C(y) is associated with the equilibrium solution to the network traffic flow problem. In a previous study we considered both mean cost, E{C(y)}, and maximum cost, $\max_y\{C(y)\}$, as useful measures of network performance. To obtain a robust strategy for network control, solutions for two extreme cases were considered. One is the *Bayes* case in which one assumes a probability density on the possible OD matrices T(y), created by estimates from traffic counts and from trip survey data, and which minimizes the expected costs. The second is the *Minimax* case for which one seeks to minimize the worst possible costs that may occur (when the O-D matrices vary in T(y)). The strategy employed is a compromise between the Bayes and the Minimax solutions and is termed the *near-Bayes near-Minimax* (NBNM) strategy. It is designed to provide performance that is close to the best that can be obtained under Bayes conditions (where the values of the origin-destination demands have an assumed known prior probability distribution), yet does not depart too far from the most beneficial controls under the most costly origin-destination demands. As such, this is a conservative approach whose controls can provide robust or risk-averse performance.

In this study we develop a more practical measure of network performance, which is the p-quantile cost (or 100-percentile cost) C_p. This is defined by the equation:

$$Prob\{C(y) < C_p\} = p$$

In mathematical terms, C_p is the p^{th} quantile of the distribution of the one-dimensional real random variable $C(y)$. In practical terms, it is a cost of traffic flow under equilibrium conditions which will only be exceeded 100(1-p) % of the time. This principle produces optimal controls such that maximum network costs are exceeded no more than in p% (a typical value being p=5%) of the cases. Such controls are designed to provide robust performance under most expected demand scenarios.

We developed a working program to compute the performance for a number of test networks. In particular, we compared the performance of the Bayes and the (Mini-) Quantile and defined a new strategy, called the near Bayes near quantile (NBNQ) , which we demonstrate to be close to both.

A copy of a more extensive Final Report can be obtained by contacting the PI or co-PIs listed above.