DEVELOPMENT OF A DEMAND UNCERTAINTY BASED MODEL TO ESTIMATE NETWORK RELIABILITY

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Introduction

The annealing step is a process of reaching a new equilibrium point after a network disturbance. In this process, a traveler will attempt to find alternative paths and capacities rather than the blocked routes. Reliability is defined as the probability that the transportation network will meet an acceptable level of service after any capacity reduction. Therefore, reliability is a subset of resiliency, one that predates the efficacy of the annealing phase.

Reliability Modeling

Consumer Surplus Reliability

Total Travel Time Reliability

Total Flow Reliability

where

\[ c_t = \sum_{i=1}^{n} c_i \]

\[ TT = \sum_{k=1}^{n} \sum_{i=1}^{m} t_i \]

\[ Flow = \sum_{k=1}^{n} \sum_{i=1}^{m} x_i \]

Supply and Demand Interaction

This study considers the effect of the perturbation on link capacity, in addition to the effects it will have on driver behavior, including potential changes in the demand function itself.

\[ x_{0t} = d_{0t} c_t \phi(\gamma) \]

\[ d_{0t} \text{ maximum demand flow between O/D pair} \]

\[ \gamma \text{ parameter of control of travel demand sensitivity with respect to travel time.} \]

\[ x_{0t} \text{ O/D travel time} \]

Sensitivity Analysis

We intend to investigate the effect that changes in both link-capacities and travelers’ responses to changing travel time have on the reliability performance. Sensitivity analysis allows us to determine the importance of each link in network and its effect(s) on performance. The links with the greatest importance are the ones that if disrupted, will have the most negative effect on network reliability.

Reliability Analysis

Reliability can be redefined as the probability that the random variables are in the acceptable region that is defined by \( G(X) > 0 \)

This study uses First Order Reliability Method (FORM), one of the most common reliability analysis methods. The basic premise behind this method is to ease the computational difficulties in approximating the performance function. For performance measurement of \( G \), network reliability is:

\[ R = \Phi(G_{MU}) \]

Where \( G_{MU} = G(\mu_c) \) for the uncertain variables \( E = E^0 \) and \( \Phi() \) is the CDF of the standard normal distribution. Each of the reliability functions that were defined earlier must be modified for use in FORM, as shown below:

\[ R_{CS} = P(\mu_c > 0) \]

\[ R_{TT} = P(\mu_t > 0) \]

\[ R_{Flow} = P(\mu_{flow} > 0) \]

Uncertainty Analysis

To simulate a real-world problem, the capacity and cost sensitivity (demand elasticity) are considered as uncertain variables. Sensitivity analysis shows the effect of each variable on intended performance measures, but does not consider these uncertainties. To quantify the effects that these uncertainties have on network performance, a separate uncertainty analysis must be performed. Total variance of performance measures, including consumer surplus, total travel time, and flow, can be estimated by using propagation of uncertainties.

\[ \sigma^2_{\mu} = \left[ \text{Var}(C) \right] \times \text{Var}(\gamma) \]

The critical link, which has the greatest effect on performance uncertainty, is identified by finding the link with highest value according to the below ratio:

\[ \ell_i = \frac{\text{Var}(C)}{\text{Var}(\gamma)} \]

Numerical Example

\[ x_{15} = 200 \exp(-\gamma_{15}) \]

\[ x_{16} = 250 \exp(-\gamma_{16}) \]

\[ \gamma \sim N(\mu, \sigma^2) = N(0.2, 0.01) \]

\[ C \sim U(0.5 C^0 - C^0) \]

Solution Algorithm

Step 1. Assign distribution to arc capacities and demand sensitivity

Step 2. Set sample number \( k=1 \)

Step 3. Generate value of uncertain parameters according to distribution properties

Step 4. Perform the network equilibrium problem

Step 5. Use sensitivity and uncertainty analysis to compute derivative and links important

Step 6. Collect statistics and compute reliability measures

Step 7. If sample number \( k \) is less than the required sample size \( K \), then increment number \( k=k+1 \) and go to step otherwise stop

More Information

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