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Using a “Bathtub Model” to Analyze Travel Can Protect Privacy While Providing Valuable Insights

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Issue

Transportation agencies increasingly rely on detailed trip data to analyze traffic patterns and plan infrastructure improvements. However, traditional data collection methods require extensive personal information about travelers’ origins, destinations, and routes, raising serious privacy concerns. Current “big data” approaches can track individual movements with alarming precision, often without explicit consent. As privacy regulations tighten and public concerns grow, transportation planners need alternative methods that balance analytical needs with privacy protection.

To address this challenge, we evaluated the “bathtub model” as a privacy-preserving alternative to traditional traffic data collection methods. This simple, network-level approach treats all trips in a region as part of one system. Instead of tracking each person’s path, a bathtub model represents trips by how much distance they have left to travel. This lets us analyze network performance while protecting privacy.

Key Research Findings

The bathtub model effectively captures network traffic dynamics while preserving traveler privacy. Unlike traditional models that require specific origin-destination

data, the bathtub model uses a unified “relative space” dimension that tracks a trip’s remaining distance rather than a physical location on a map. For example, two travelers on very different routes might both have five miles left to reach their destinations; in the model, they are treated the same. This approach eliminates the need to collect or store detailed route information, substantially reducing privacy risks while still providing valuable network performance measures, such as demand, delay, and throughput.

The bathtub model was successfully validated using public bike-sharing data. We tested the unified relative space paradigm, conservation equations, and the generalized bathtub model using travel data from Boston’s Bluebikes system. Results showed perfect accuracy for total trip conservation (i.e., the total number of trips in the system from start to finish) and good accuracy for trip-miles traveled, confirming the model’s mathematical soundness and practical value.

Computational needs are low, enabling rapid assessments. Because the bathtub model views the transportation network macroscopically rather than tracking individual street segments, it drastically reduces the complexity of data processing. Agencies can run quick diagnostics, screen scenarios, and support near-term planning without expensive data pipelines.

Implications for Policy and Practice

Based on our research, transportation agencies may want to consider the following applications of the bathtub model:

Design privacy-enhancing data collection protocols.

Since the bathtub model only requires trip start times, end times, and distances, agencies could update data collection protocols to avoid storing sensitive location details. This aligns with stricter privacy regulations and reduces liability risks.

Use the model for accurate yet efficient system monitoring.

Our tests showed the bathtub model preserves total trip counts and performs well in estimating trip-miles traveled. Agencies could apply it for routine network performance checks, pilot evaluations, and preliminary planning studies where quick and reliable results are needed.

Reduce computational costs in planning analyses.

Because the model treats the system as a whole rather than tracking every street segment, agencies can run analyses with far fewer resources—supporting more frequent monitoring or faster responses to emerging issues.

Build public confidence in transportation data programs.

By demonstrating that individual trips cannot be traced, agencies could increase public willingness to participate in data collection efforts, improving both the quality and representativeness of available data.

More Information

For more information, please see the report, “Development of New Privacy-preserving Method for Traffic Data Collection and Analysis: The Bathtub Model Approach,” available at <https://www.ucits.org/research-project/2022-45/>.

For theoretical foundations, see our companion paper: “Monotone three-dimensional surface and equivalent formulations of the generalized bathtub model,” available at arXiv:2505.10014.

Contact Wen-Long Jin at wjin@uci.edu with questions or for additional information about implementing privacy-preserving traffic data collection methods.

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