February 2024

NATIONAL INSTITUTE FOR CONGESTION REDUCTION

POLICY BRIEF

Multi-stage Models for Dynamic Ride-Sharing in Taxi Services and Congestion Analysis

Luca Quadrifoglio, Cheng Zhang, Min-Ci Sun
Texas A&M University
Maria Laura delle Monache, Yuneil Yeo
University of California, Berkeley

For more information, contact: Luca Quadrifoglio
Email: quadrifo@tamu.edu

BACKGROUND AND OBJECTIVES

Large and growing urban areas are facing an escalation of traffic congestion and all its consequences in terms of overall delay experienced by travelers. Ridesharing is intuitively a practical solution to improve the congestion issues in our modern cities. The largely unused capacity of the private vehicles would be utilized in place of other vehicles to satisfy the mobility needs of individual passengers.

This project analyzes and quantifies the effect on congestion reduction of a large-scale application of ridesharing mode to serve metropolitan transportation demand of taxi services, which have been shown to be often unproductive in the taxi capacity. Specifically, we are evaluating the benefit of converting a sizeable portion of taxi rides from conventional direct point-to-point service to a ridesharing modality. This can potentially lead to a significant reduction of vehicles on the network and consequently ease out congestion at the expense of the service level experienced by ride-sharing participants.

This study introduces a practical and achievable model that systematically matches multiple riders, thereby enhancing taxi operation performance. The long-term goal is to attract the interest of taxi companies and government agencies to promote ride-sharing with multiple riders as a strategy. This is particularly important given the growing public awareness of environmental issues and the need for sustainable cities.

This policy report outlines the principles and guidelines for implementing ride-sharing initiatives, with a focus on taxi operation, as a means to alleviate traffic congestion, reduce car ownership, and promote sustainable transportation. The policy incorporates factors at both the individual and system levels, with the aim of maximizing the advantages of ride-sharing.

METHODOLOGY

This project proposes a multi-stage ride-sharing model to pair riders. Afterward, congestion analysis is adopted to qualify the benefit from the whole city view.

1. Multi-stage Ride-Sharing Models

This study uses insertion methods to identify potential matches and establish the sequence of pick-up and drop-off points, transforming the ride-sharing problem into a network optimization problem. Three elements are considered to define a feasible match, including (i) distance savings, (ii) drivers' parking time and riders' waiting time, and (iii) riders' detour tolerance. Afterward, we employ the greedy algorithm and optimization approach to determine the selection of links in the network. To accommodate more than 2 riders in a match, we propose a multi-stage model to merge unpaired riders into existing pairs. The matching process is illustrated in Figure 1.

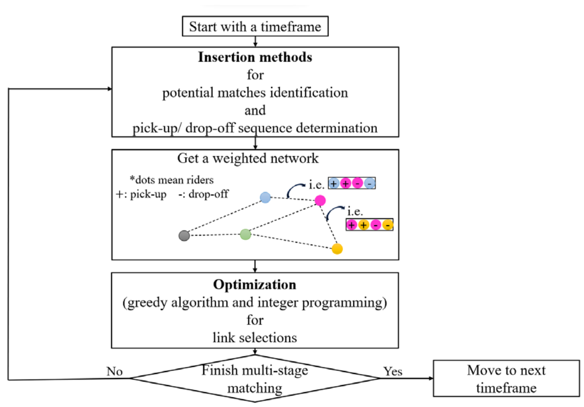

Figure 1 The procedure of the proposed multi-stage model

 DOI: doi.org/10.5038/CUTR-NICR-Y3-2-8

2. Congestion Analysis

Through the congestion analysis, the traffic congestion status of the City of Chicago for each 15-minute interval before and after the ride-sharing is assessed. We compute the integrated congestion index based on the mean velocity and congested vehicle miles traveled (VMT) ratio. The congestion index for this project is 0 for "Heavy Congestion," 1 for "Medium Congestion," 2 for "Light Congestion," and 3 for "No Congestion."

The mean velocity of an area is computed by (i) extracting possible areas crossed by a vehicle for each trip, (ii) weighting the mean velocity of trips based on trip duration and trip distance, and (iii) adjusting the mean velocity of an area based on past mean velocity and its neighboring areas' mean velocities through the least square model.

Unlike mean velocity, the congested VMT ratio is computed for the entire city of Chicago and for each time period (morning non-rush hour, morning rush hour, afternoon non-rush hour, afternoon rush hour, and night). As the segment with a speed greater than 20 mph is considered "no congestion" or "light congestion," congested VMT is VMT of trips with a speed less than 20 mph. The congested VMT ratio is then the ratio of congested VMT and total VMT.

With fuzzy logic and membership function, the membership degree to each congestion index is defined based on mean velocity and congested VMT ratio separately. The combined membership degree for each congestion index is then computed as the weighted sum of the membership degrees. Since the mean velocity has a higher spatial and temporal precision, greater weight is given to the membership degree for the mean velocity. The integrated congestion index is chosen by finding the congestion index with the largest combined membership degree. Based on the integrated congestion index, the congestion map of the city of Chicago is plotted.

RESEARCH FINDINGS

This study proposes a multi-stage optimization model to match taxi riders, aiming to minimize the total travel distance while ensuring the satisfaction of riders (waiting time and detour tolerance). Some findings are observed from this study:

1. Applied to taxi data in Chicago, the multi-stage model has a significant reduction in total travel distance with the overall distance decreasing by 55.00 % with the greedy algorithm.
2. The proposed insertion method that merges two 2-ride pairs into 4-rider matches explores more permutation probabilities, further enhancing the matching of 4-rider groups and reducing total travel distance.
3. Passengers' preferences, including their acceptable waiting time and detour tolerance, are critical to the overall performance. Particularly, the extension of riders' waiting time can enhance the success of ride-sharing matching.
4. Detour tolerance has a great impact on distance reduction as it directly affects the acceptable distance of riders. When the ratio reaches 1.25, there are significant savings in distance as more riders can be paired together. However, the improvement becomes less noticeable when the value exceeds 1.5 as the riders have been paired with others nearby with nearby companions.

POLICY AND PRACTICE RECOMMENDATIONS

The promotion of ride-sharing can contribute to the creation of a sustainable transportation solution. By following these guidelines, our goal is to encourage widespread adoption, alleviate traffic congestion, and play a role in shaping efficient and equitable transportation systems.

1. **Incentive Schemes**
   Rider matching operates on the basis of distance savings. Therefore, if these savings can be translated into monetary rewards for riders, it would likely enhance their willingness to opt for ride-sharing.
2. **Public Awareness Campaigns**
   The government can initiate awareness campaigns, educating the public about the advantages of ridesharing and addressing concerns related to cost savings, environmental impact, and diminished traffic congestion.
3. **Integration with Public Transportation**
   The taxi companies can promote a smooth blend of ridesharing services with public transportation, offering commuters seamless and convenient multi-modal travel choices.

For more information on this project, download the entire report at nicr.usf.edu or contact **nicr@usf.edu**

NICR
NATIONAL INSTITUTE FOR CONGESTION REDUCTION

facebook.com/NationalInstituteforCongestionReduction