Measuring and Optimizing the Network Disequilibrium Levels through Ride-sourcing Vehicle Data

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Real-world traffic networks

- The public agencies and transportation researchers know little about real-world real-time traffic conditions.
  - Traffic speed, traffic volume are known
  - Route choices, departure time and traffic demand are still challenging to obtain
- Does Dynamic User Equilibrium hold in day-to-day traffic?
- How to manage the traffic with real-time data?
Ride-sourcing services

- More than $600B questions can be addressed by ride-sourcing services
  - Car as a service ($110B)
  - Core taxi-cab market ($100B)
  - Public transportation service ($175B)
- Uber has operations in 785 metropolitan areas worldwide
- Didi Chuxing processes 4,875TB data and archives 106TB trajectory data per day
Motivation

Is there a way to collaborate?

▶ Is there a way to collaborate?
  ▶ *For TNCs*: Provide data without damaging their interests
  ▶ *For public agencies*: Use the data to manage the traffic and reduce congestion
Contributions

A holistic traffic management framework:

- Measure of network disequilibrium level (NDL)
- NDL can be estimated using ride-sourcing vehicle (RV) data
- A data disclosure scheme for TNCs to release ride-sourcing vehicle (RV) data
- Traffic management method using NDL
Dynamic User Equilibrium

- No traveler can improve their travel time by unilaterally changing their route and departure time
- Complementarity problem

\[ F_{rs}^k(t) \left( C_{rs}^k(t) - \Pi_{rs}(t) \right) = 0, \forall k \in K_{rs}, rs \in K_q, t \]

where

\[ \Pi_{rs}(t) = \min_{k \in K_{rs}} C_{rs}^k(t), \forall rs \in K_q, t \]
Network Disequilibrium Level (NDL)

\[
D^M_{rs}(t) = \sum_{k \in K_{rs}} F^k_{rs}(t) \left( C^k_{rs}(t) - \Pi_{rs}(t) \right)
\]

\[
D^F_{rs}(t) = \sum_{k \in K_{rs}} p^k_{rs}(t) \left( C^k_{rs}(t) - \Pi_{rs}(t) \right)
\]

- \(D^F_{rs}(t)\) is free of path flow
- Merit function in Dynamic User Equilibrium
- OD based, time-dependent
- Challenging to evaluate
Estimate the NDL using RV trajectory

Facts:

- RV penetration rate 1% ~ 10% in total traffic flow, growing
- Representative: route choice behaviors of RVs are similar to the conventional vehicles (from picking up to dropping off)
- Travel time of a RV in path $k$ for OD $rs$ is an unbiased estimator of $C^k_{rs}$

We can construct an estimator of NDL using RV trajectory data.
Estimate the NDL using RV trajectory

The duration of trajectory $i$ is denoted by $\gamma_i$

$$\gamma_i = t_i^{T_i-1} - t_i^0$$

If trajectory $i$ departs from $r$ and arrives at $t$ at time $t$, then

$$\mathbb{E}(\gamma_i) = \sum_{k \in K_{rs}} p_{rs}^k(t) C_{rs}^k(t)$$

Then we define

$$D_{rs}^D(t) = \frac{1}{|N_{rs}(t)|} \sum_{i \in N_{rs}(t)} \gamma_i - \min_{i \in N_{rs}(t)} \gamma_i$$

$$\rightarrow C_{rs}(t) - \Pi_{rs}(t)$$

$N_{rs}(t)$ represents the set of trajectories departing at $t$ from $r$ to $s$. Then

$$D_{rs}^D(t) \xrightarrow{P} D_{rs}^F(t)$$
Data privacy and zone-to-zone travel time

To computed the NDL estimator, we need pick-up and drop-off location and time.

- The data might reveal the drivers and riders’ personal information
- The data can estimate the revenue of TNCs

To ensure data privacy:

- We develop a data sharing scheme to convert the trajectory data to zone-to-zone travel time
- The disequilibrium level can be estimated from zone-to-zone travel time data
Traffic Management using NDL

- NDL represents the gap between current traffic conditions and DUE
- Minimizing NDL $\rightarrow$ User optimal routing
- Alway control the vehicle with largest NDL $\rightarrow$ Optimal control effects
Trajectories of all RVs operated by DiDi chuxing from Nov. 1st, 2016 to Nov. 30th, 2016
NDL pattern

- General trend, day-to-day variation
- NDL patterns are similar to demand pattern (which is not always the case)
Hourly zone-to-zone travel time within Allegheny county from Jan. 1st, 2016 to Jun. 30th, 2017

Average travel time to destination zone: 4min 21sec
NDL patterns

NDL pattern differs from demand pattern (Pittsburgh is not a tourist city)

- NDL relatively stable on weekdays
- NDL is unstable on weekends
Traffic management

- We calibrate the traffic flows, route choice model and OD demand in Pittsburgh metropolitan area (traffic volume, INRIX speed)
- Controlling 1% of the vehicle will reduce the total network congestion by around 7%.
Thanks! Questions and comments?

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