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

Is there a way to collaborate?

VS

- 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)

$$D_{rs}^{\mathcal{M}}(t) = \sum_{k \in K_{rs}} F_{rs}^{k}(t) \left(C_{rs}^{k}(t) - \Pi_{rs}(t) \right)$$

$$D_{rs}^{\mathcal{F}}(t) = \sum_{k \in K_{rs}} p_{rs}^{k}(t) \left(C_{rs}^{k}(t) - \Pi_{rs}(t) \right)$$

- $D_{rs}^{\mathcal{F}}(t)$ 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% $\sim$ 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_{rs}^{k}

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 γ_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

$$\begin{aligned} D_{rs}^{\mathcal{D}}(t) &= \frac{1}{|N_{rs}(t)|} \sum_{i \in N_{rs}(t)} \gamma_i - \min_{i \in N_{rs}(t)} \gamma_i \\ &\rightarrow C_{rs}(t) - \Pi_{rs}(t) \end{aligned}$$

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

$$D_{rs}^{\mathcal{D}}(t) \xrightarrow{P} D_{rs}^{\mathcal{F}}(t)$$

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:

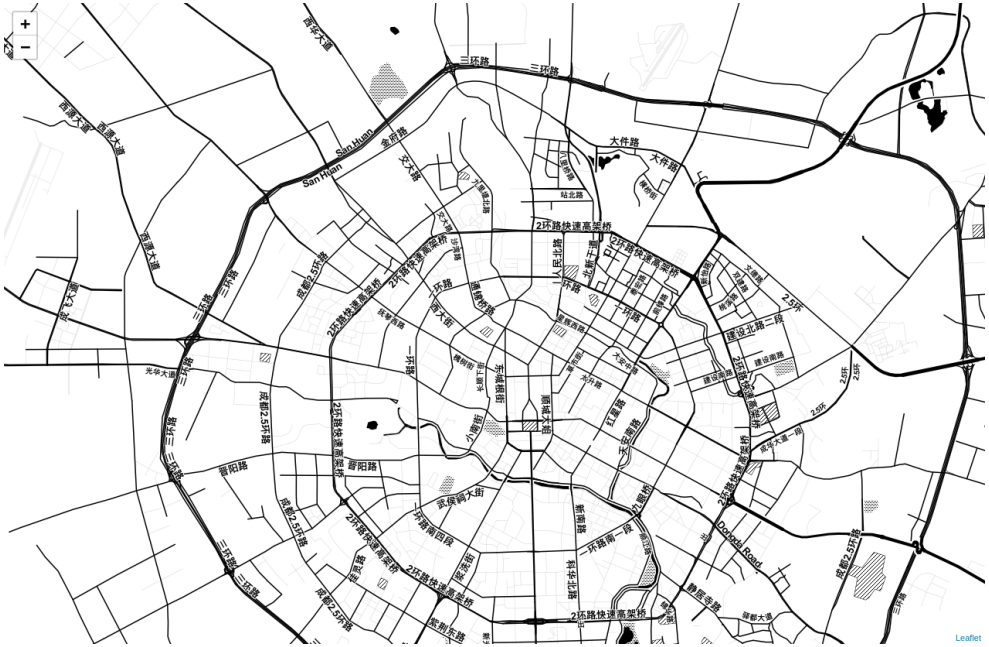
- We develop a data sharing scheme to convert the trajectory data to zone-to-zone travel time
- The disequilibrium level can be estimated from zone-to-zone travel time data

Traffic Management using NDL

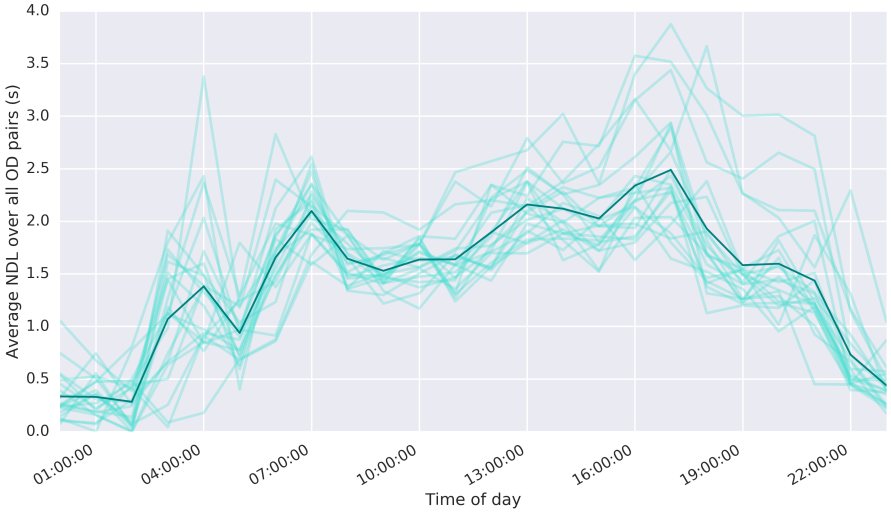
- NDL represents the gap between current traffic conditions and DUE
- Minimizing NDL $\rightarrow$ User optimal routing
- Alway control the vehicle with largest NDL $\rightarrow$ Optimal control effects

Didi Chuxing in Chengdu

- Trajectories of all RVs operated by DiDi chuxing from Nov. 1st, 2016 to Nov. 30th, 2016



NDL pattern



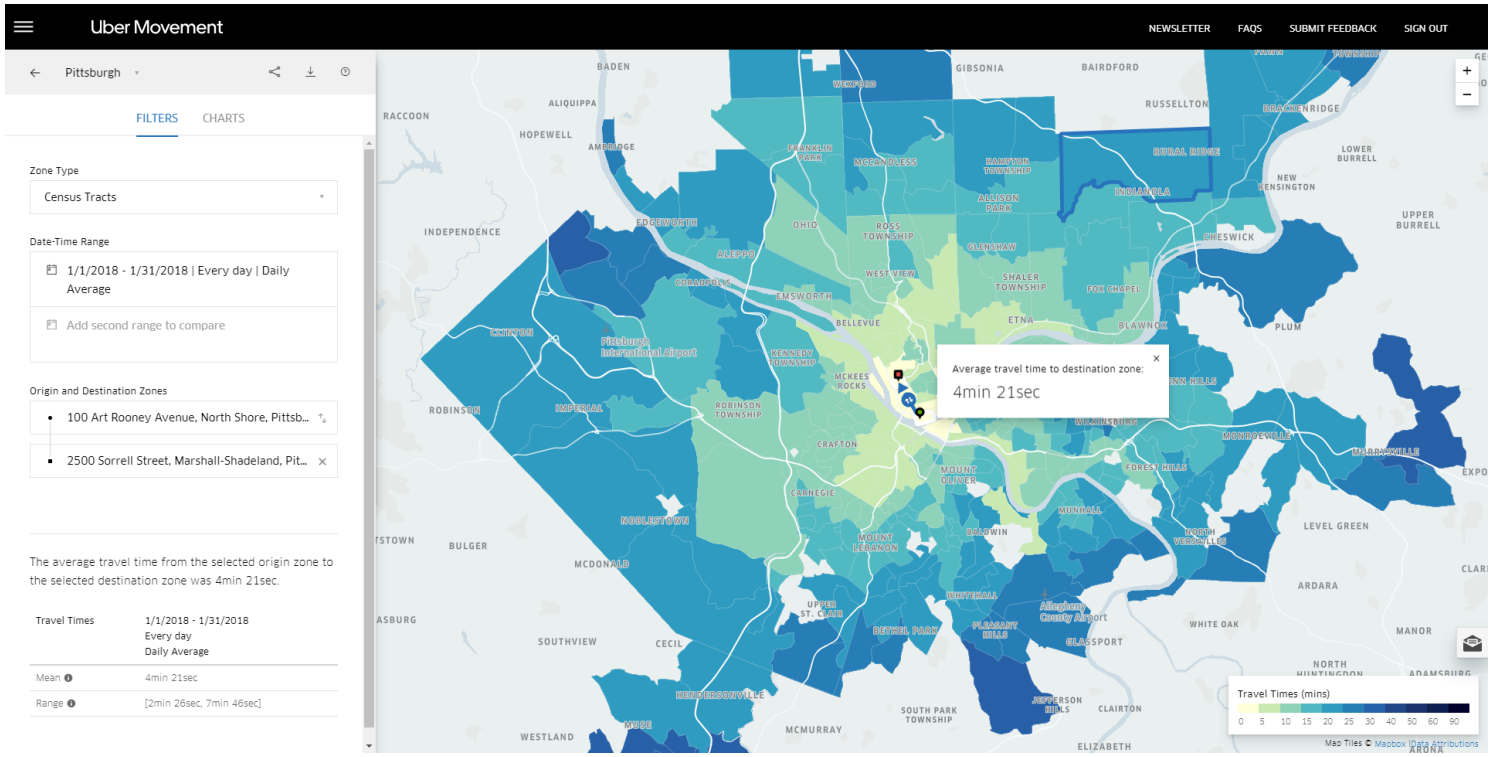
(a) Weekdays

(b) Weekends

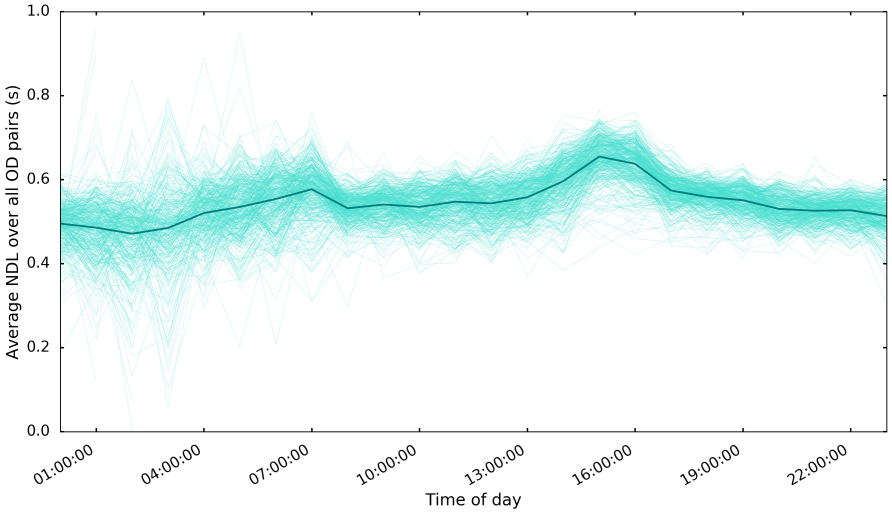
- General trend, day-to-day variation
- NDL patterns are similar to demand pattern (which is not always the case)

Uber in Pittsburgh

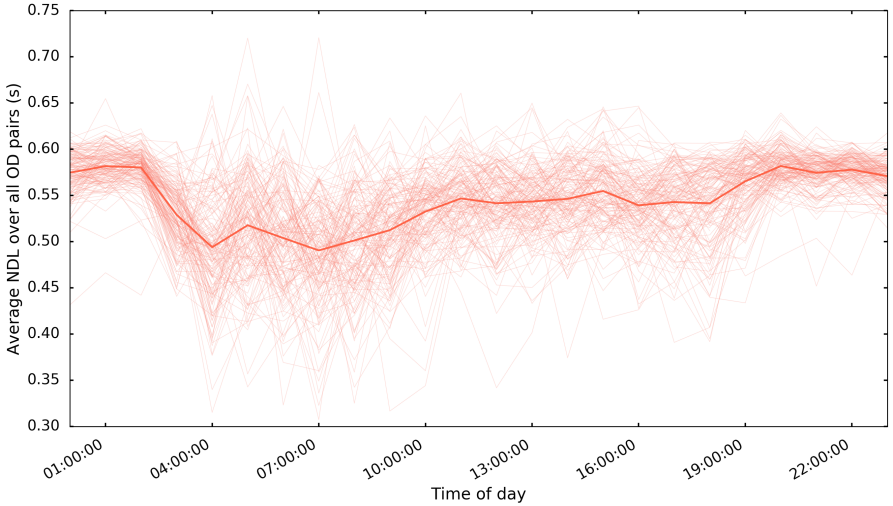
- Hourly zone-to-zone travel time within Allegheny county from Jan. 1st, 2016 to Jun. 30th, 2017



NDL patterns



(a) Weekdays



(b) Weekends

- 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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