Decentralized Cooperative Search Routing in Ride-sourcing Systems

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General View

Decentralized search routing application in transport:

- ✓ Cruising taxis searching for waiting passengers
- ✓ Vehicles looking for stationary parking locations
- ✓ Communication lost in ride-sourcing/ride-sharing companies' platform

Mobile agents looking for stationary resources

What makes a difference?

1. **Level of available information**
2. **Endogenous existence of competition**

Problem Statement

Decentralized Cooperative Search Routing in Ride-sourcing Systems

3. **Vacant Ride-sourcing vehicles' movements**

2. **No Competition**

   Ride-sourcing vehicles do not compete (i.e. they obey the **static** recommendations from ride-sourcing system).

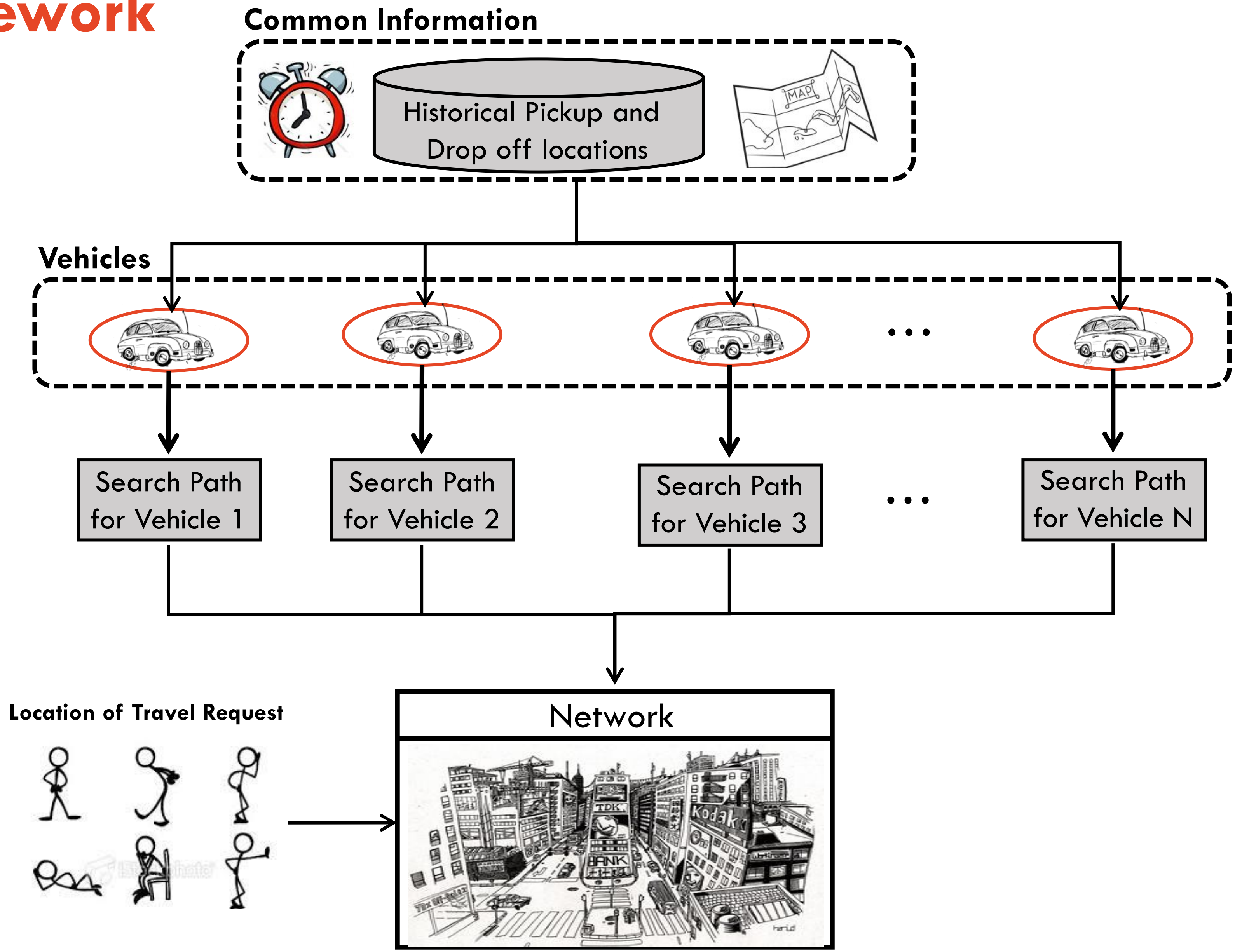
1. **No Communication**

   Ride-sourcing vehicles do not have any information (e.g. fleet size, vehicles' location) about other vehicles

Goal

- ✓ Reduce passenger waiting time/expiration rate
- ✓ Reduce ride-sourcing vehicles' search time

Framework


Common Information
Historical Pickup and Drop off locations
MAP
Vehicles
...
Search Path for Vehicle 1
Search Path for Vehicle 2
Search Path for Vehicle 3
...
Search Path for Vehicle N
Location of Travel Request
Network

Methodology (Overview)

- **Partitioning the network into homogenous regions in terms of attractiveness**
  - ✓ Definition of the attractiveness as a measure for decentralized search problems
  - ✓ Considering spatial limitation (e.g. connectivity, total coverage area)
  - ✓ Homogeneity vs. number of the regions

- **Hierarchical search routing**
  - ✓ Aggregating the attractiveness for each region
  - ✓ Separating the movements into:
    - intra-regional
    - inter-regional

Methodology (Partitioning)

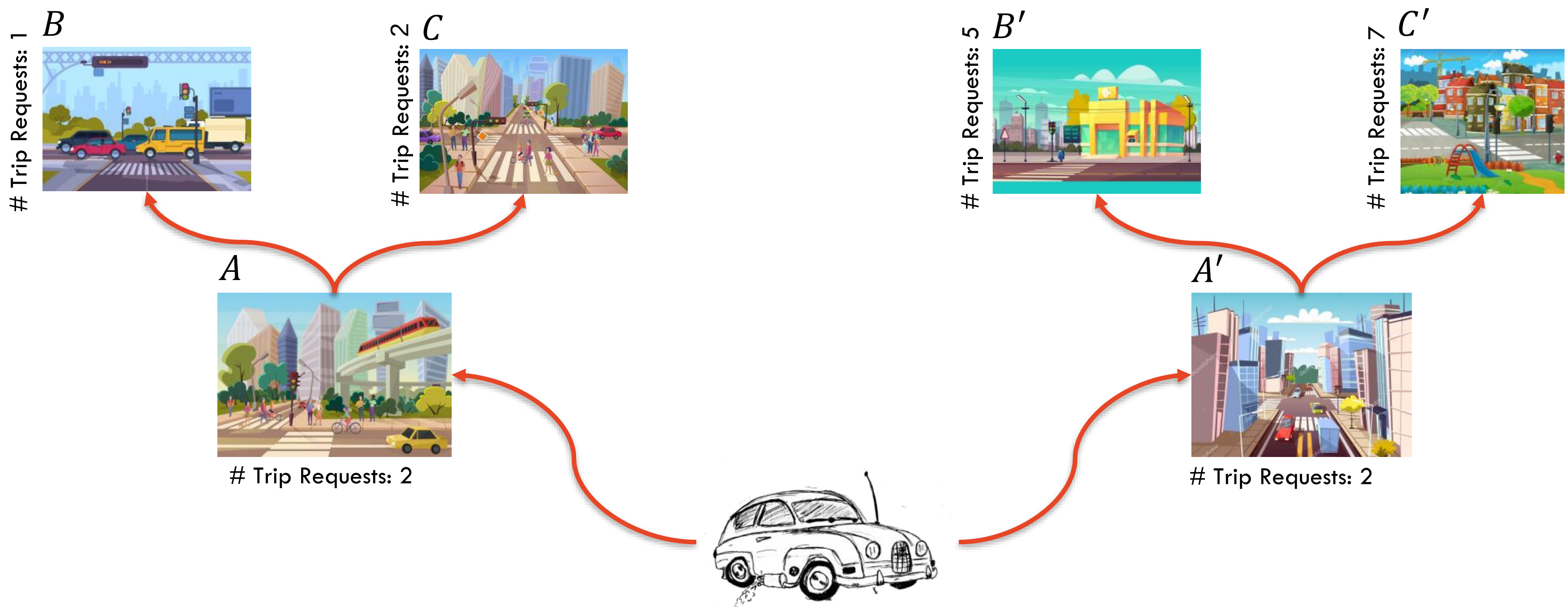
Attractiveness

<u>Goal:</u> Considering cumulative probability of finding passengers

What if we consider only the temporal aggregation of travel request's *<u>origin</u>*?

Are road A and road A' equally important in routing vacant vehicles?

"Importance of a road must be defined based on the importance of other roads that has travel request originated from it"



Methodology (Partitioning)

Attractiveness as the proposed measure

How to consider overall probability of finding passengers? **Page rank**

"PageRank works by counting the number and quality of links to a page to determine a rough estimate of how important the website is. The underlying assumption is that more important websites are likely to receive more links from other websites [1]*."*

$$PR(u) = \sum_{v \in B_u} \frac{PR(v)}{C(v)}$$

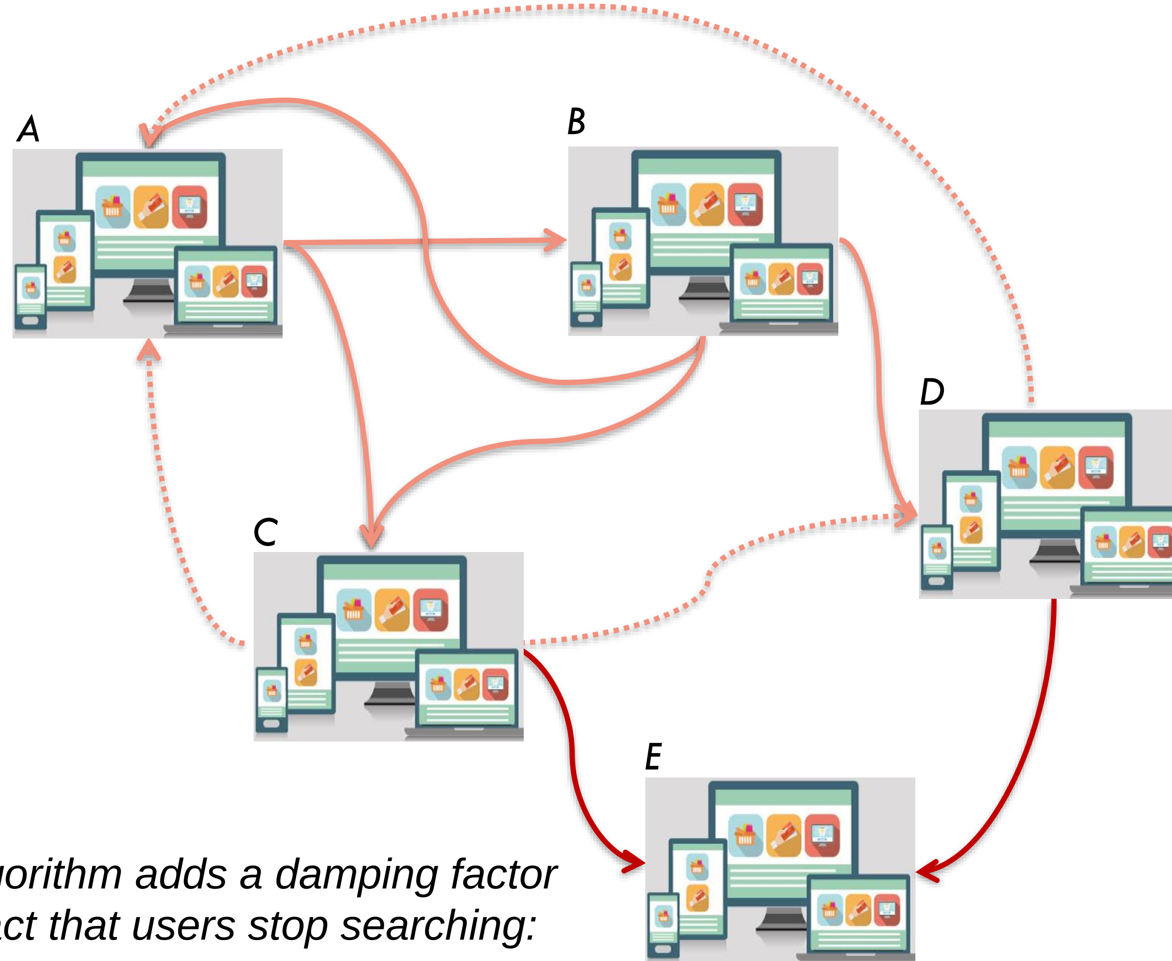
- ✓ $PR(u)$: Page rank value of page u
- ✓ B_u: Set of all pages linking to page u
- ✓ $C(v)$: Number of links from page v

[1]. Page, Lawrence, Sergey Brin, Rajeev Motwani, and Terry Winograd. *The PageRank citation ranking: Bringing order to the web*. Stanford InfoLab, 1999.

Methodology (Partitioning)

Attractiveness as the proposed measure

$$PR(E) = \frac{PR(C)}{3} + \frac{PR(D)}{2}$$



We do not know PR of each page until we do not know the PR of pages pointing to **them** !!

In practice, the Page Rank algorithm adds a damping factor at each stage to model the fact that users stop searching:

$$PR(u) = (1 - d) + d \sum_{v \in B_u} \frac{PR(v)}{C(v)}$$

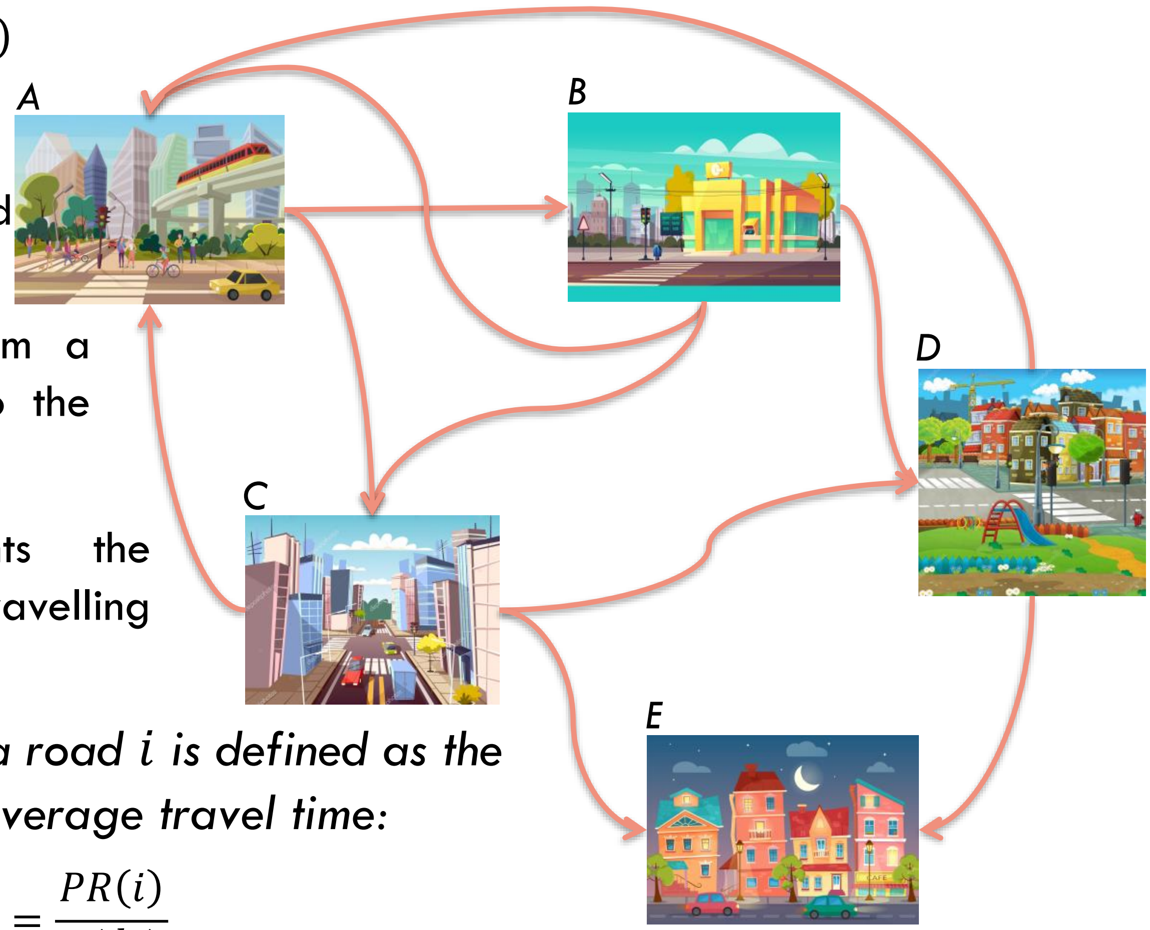
Methodology (Partitioning)

Attractiveness as the proposed measure

Page Ranking as an attractiveness measure:

The weighted directed graph $G(V, E)$ is built such that:

- ✓ each vertex, V, represents a road with a unique road ID
- ✓ each edge, E, is directed from a waiting passenger <u>destination</u> to the corresponding <u>origin</u>
- ✓ associated weighting represents the demand or volume of resources travelling between the roads

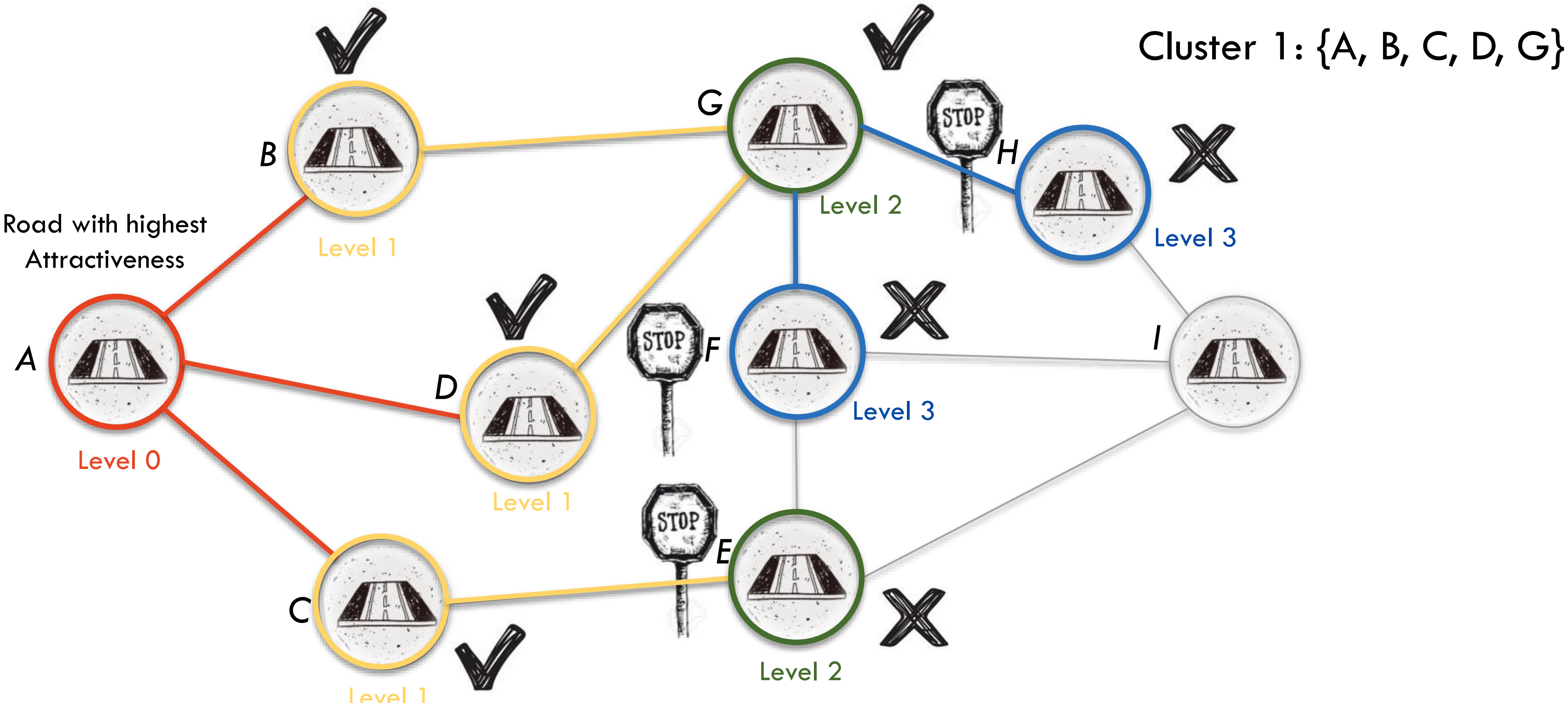


The attractiveness measure A_i for a road i is defined as the ratio of its PageRank score to its average travel time:

$$A_i = \frac{PR(i)}{T_i} = \frac{PR(i)}{r\left(\frac{l_i}{v_i^*}\right)}$$

Methodology (Partitioning)

Traverse Method for Considering Connectivity



A criteria is not satisfied by adding a road ✗

A criteria is satisfied by adding a road ✓

Methodology (Partitioning)

Criteria for Considering Homogeneity and cluster size

Criteria of selecting a section into a cluster:

- ✓ Variation in standard deviation after adopting a section

$$\Delta\sigma_k = \sqrt{\sigma_k^2} - \sqrt{\sigma_{k-1}^2} \leq \Theta_0 \left(\frac{1}{2}\right)^n$$

k: number of the roads in the current cluster
n: number of existing cluster

$$\bar{x}_k = \bar{x}_{k-1} + \frac{x_k - \bar{x}_{k-1}}{k}$$

$$\sigma_k^2 = \sigma_{k-1}^2 + \frac{(x_k - \bar{x}_{k-1})(x_k - \bar{x}_k) - \sigma_{k-1}^2}{k}$$

x: attractiveness in the current cluster

Minimum of cluster size:

- ✓ Add roads to a current cluster until reaching the minimum size
- ✓ Merge clusters when the number neighboring roads are not enough

Maximum of cluster size:

- ✓ Stop adding roads once reaching to the maximum limit
  (scanning order is in a descending sequence)

Methodology (Routing)

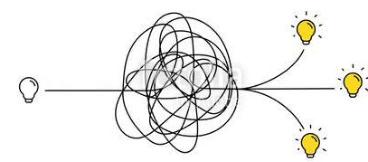
Ride-sourcing vehicles need to choose a destination road under two scenarios:

✓ after reaching to the destination of passengers (intra-regional)

(Random destination)

✓ after an ineffective search in each region (inter-regional)

(Utilizing Logit Model based on aggregated attractiveness)



Spatial Regional Aggregating of attractiveness:

$$A_{C_I} = \frac{\sum_{i \in C_I} PR(i)}{\sum_{i \in C_I} T_i}$$

C_I is the cluster of interest and i is the index for roads that are classified in the cluster C_I.

Methodology (Routing)

Ride-sourcing vehicles need to choose a destination road under two scenarios:

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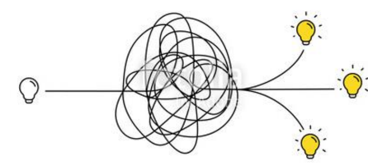


- ✓ after an ineffective search in each region (inter-regional)

  (Utilizing Logit Model based on aggregated attractiveness)

Logit Choice Model:

the probability for choosing a cluster C_I as the destination

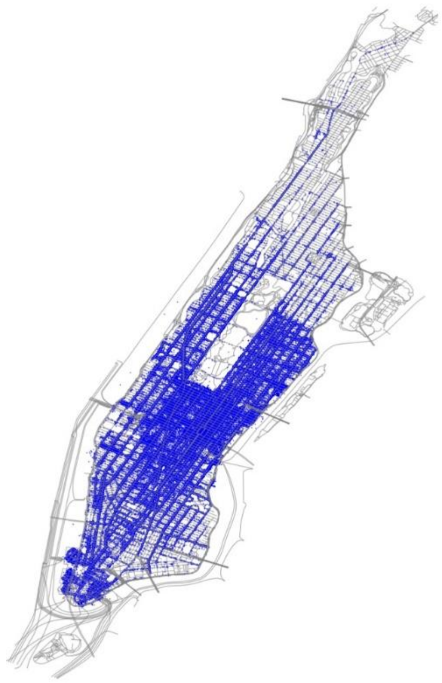
$$P_{C_I} = \frac{e^{\beta A_{C_I}}}{\sum_{C_J=1}^{C_N} e^{\beta A_{C_J}}}$$

β is the scaling constant

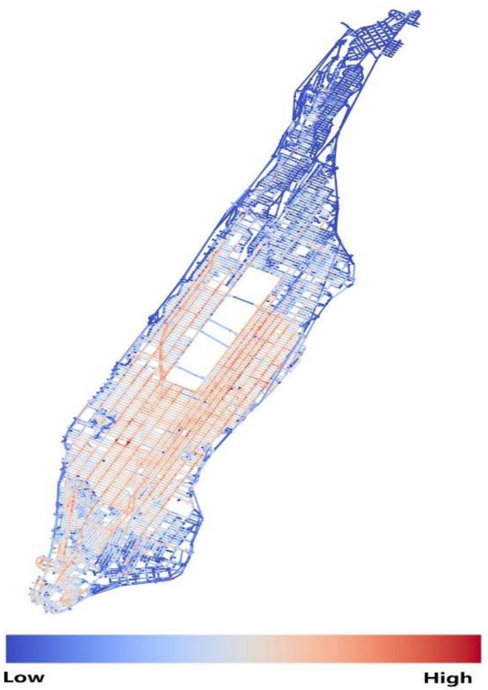
Results

Pick-up Volumes and Obtained Attractiveness

✓ 21 working days from May 2016 for the training and choosing 5 random days from June 2016 for testing (NYC TLC data set)



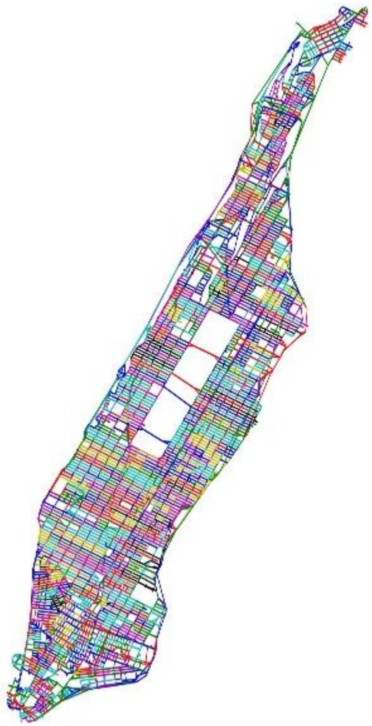
Peak-hour taxi pick-up volumes



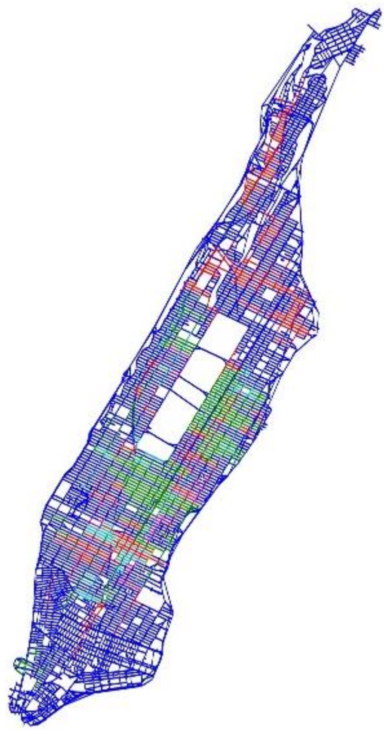
Corresponding link attractiveness

Results

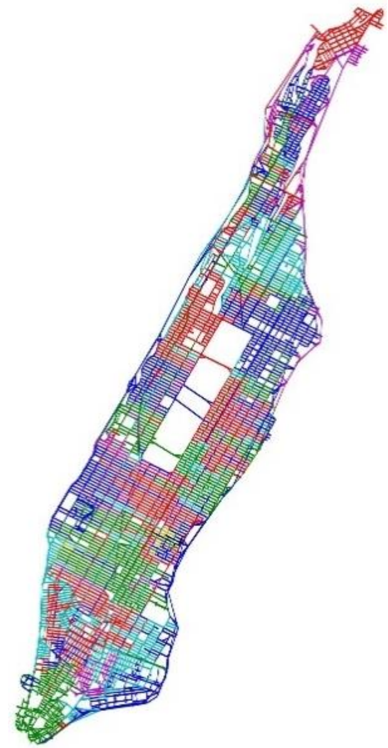
Partitioning based on attractiveness



Fixed threshold and no cluster size cap (383 clusters)



Varying threshold and no cluster size cap (48 clusters)

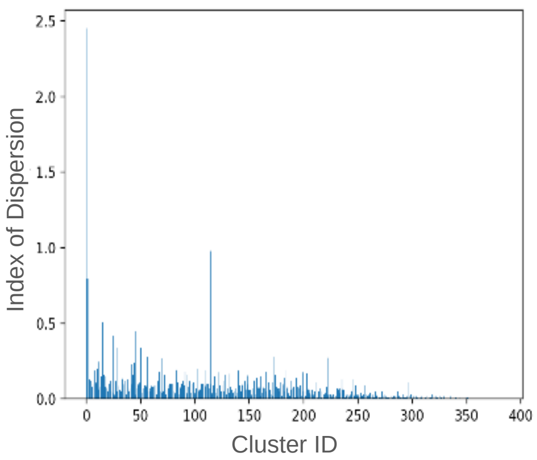


Varying threshold and cluster size cap equal to 400 (77 clusters)

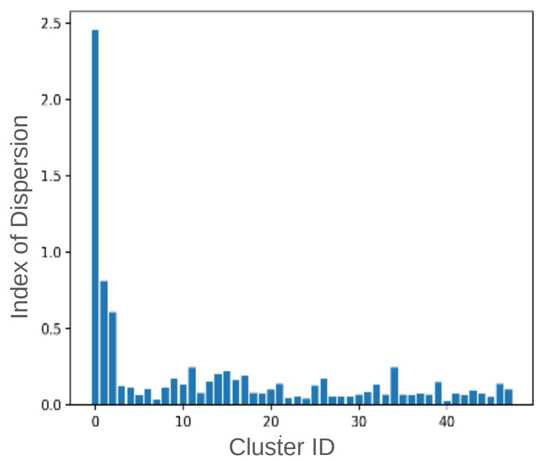
Results

Investigating the homogeneity

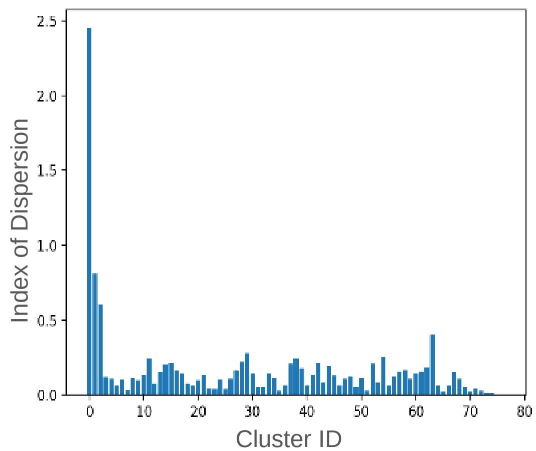
- ✓ Index of dispersion without partitioning: 0.445



Fixed threshold and no cluster size cap



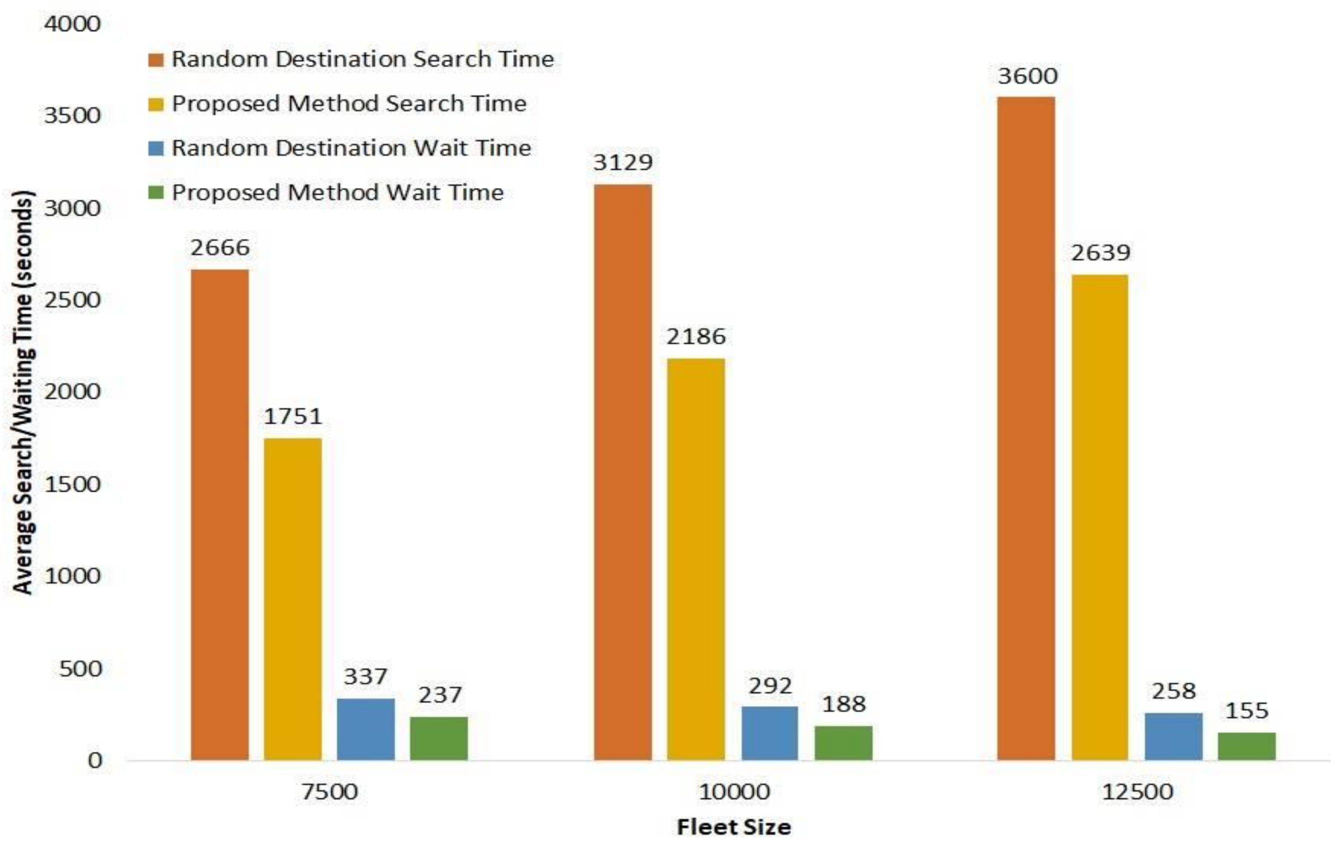
Varying threshold and no cluster size cap



Varying threshold and cluster size cap equal to 400

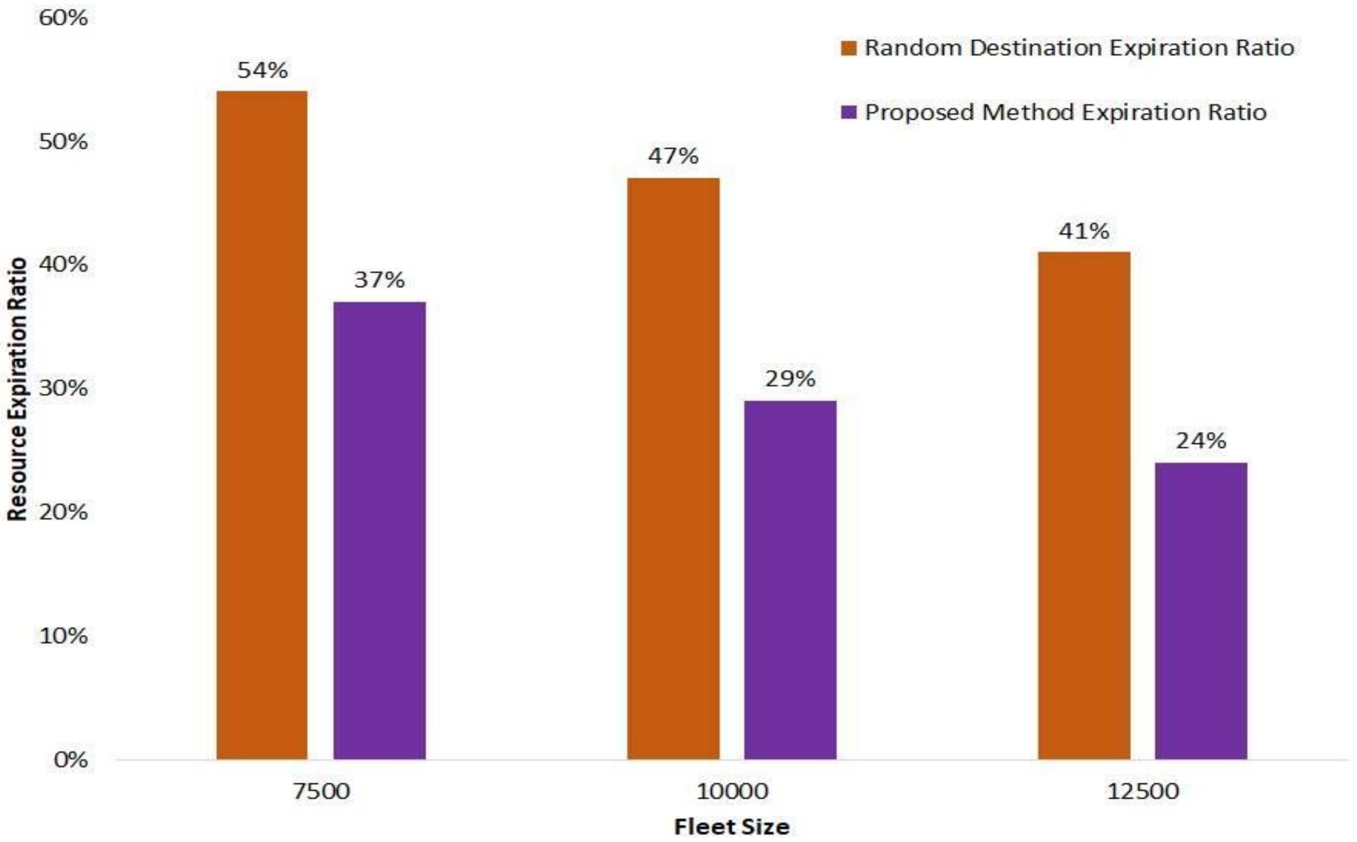
Results

Investigating Waiting Time of Passengers and Search Time of Vehicles



Results

Investigating Expiration Rate of Passengers



Results

Proposed method vs. random destination

Method	Fleet Size	Average Agent Search Time [Sec]	Average Resource Wait Time [Sec]	Resource Expiration Percentage	Total Number of Assignments
Random Destination	7500	2666	337	54%	117571
	10000	3129	292	47%	137286
	12500	3600	258	41%	152130
Proposed Method	7500	1751	237	37%	159768 (35.8%)
	10000	2186	188	29%	179844 (30.1%)
	12500	2639	155	24%	197319 (29.7%)

Discussion

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