Spatial Temporal Rush-Hour Traffic Local Co-location Detection and Spatial Equity

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Problem Statement

Inputs

- Geolocated traffic events
- Time-stamped records
- Community-level spatial partitions
- Demographic and exposure data

Outputs

- Spatial temporal local co-location traffic pattern
- Identification of spatial equity

Objectives

- Find out the traffic pattern and community resource distribution. And provide suggestions to the policy

Significance of Problem

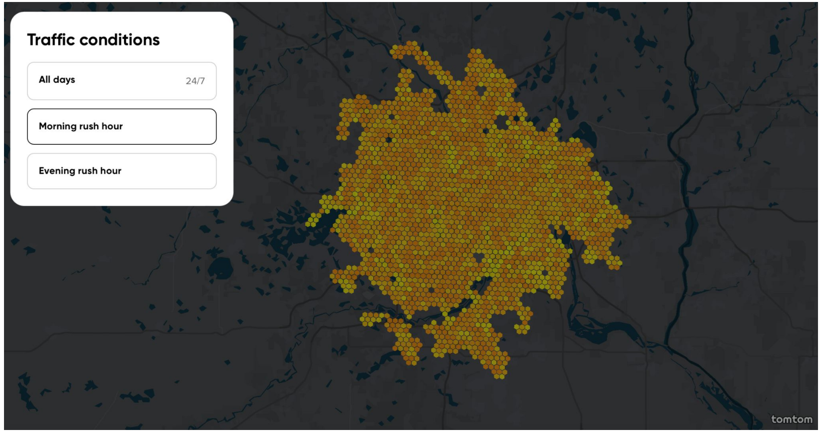
- Rush-hour traffic creates concentrated risk in specific locations and time periods.
- Some communities may experience higher traffic exposure than others.
- Identifying the traffic spatial temporal pattern helps discover the spatial inequality.
- Research results support better traffic plan and policy making.

Challenges

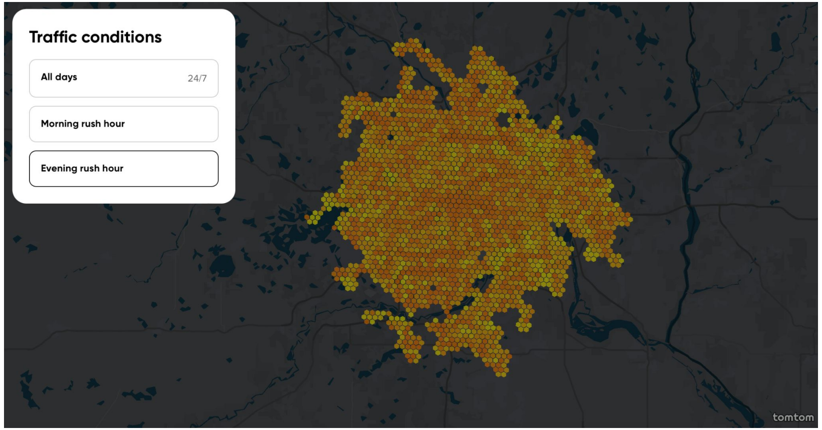
- Averaging traffic data may hide rush-hour patterns.
- Fair comparison across communities requires population normalization.
- Detecting high-density traffic zone and calculating population are challenging.

Proposed Approach

- Detect the **rush-hour traffic** risk pattern.
- Utilize co-location technique to find out the high-density traffic location.



Morning rush-hour



Evening rush-hour

[Tomtom traffic index]

Proposed Approach

- Extend participation index by taking **time dimension** into consideration.
- Fix the time on the rush-hour so that the index would not be averaged out.

Participation Rate & Participation Index

$$PR(C, f_i) = \frac{|I(C, f_i)|}{|I(f_i)|}$$

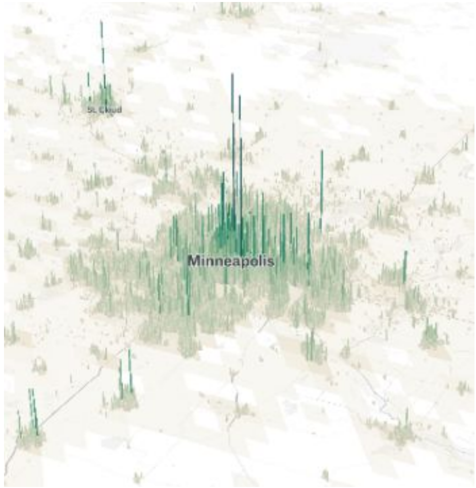
$$PI(C) = min_{f_i \in C} PR(C, f_i)$$

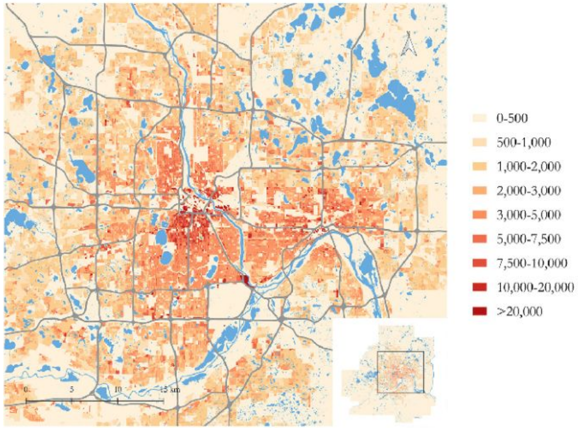
If considering time

$$PI(C, t) = min_{f_i \in C} PR(C, f_i, t)$$

Proposed Approach

- Introduce **demographic baseline** as equity-aware normalization.
- Divide each PI by the population ratio for each community as normalization.
- Then we call the result as Equity-aware Participation Index(EPI).
- This index is used to evaluate the disproportionate traffic risk.





3D view of population density

2D view of population density

*Population density in Minneapolis

$$EPI(C,r,t) = \frac{PI(C,t)}{w_r} \quad \text{where } w_r = \frac{Pop_r}{Pop_{total}}$$

*EPI, w are defined by ourselves

*Pop: population

Proposed Approach

- Utilize **statistical inference** and **permutation test** to examine the spatial equity between communities.
- Introduce Resource Availability(RA), representing the specific resource nearby the community.
- Visualize the spatial equity.

$$x_i = log\left(\frac{EPI_i}{RA_i}\right) \text{ where } RA_i = \frac{F_i}{Pop_i}$$

$$H_0 : \mathrm{Var}(x_1, x_2, \ldots, x_n) = 0$$

$$H_1 : \mathrm{Var}(x_1, x_2, \ldots, x_n) > 0$$

*RA, F are defined by ourselves
*F: facilities

$$x_i^{(b)} = \log\left(\frac{EPI_i}{RA_i^{(b)}}\right)$$

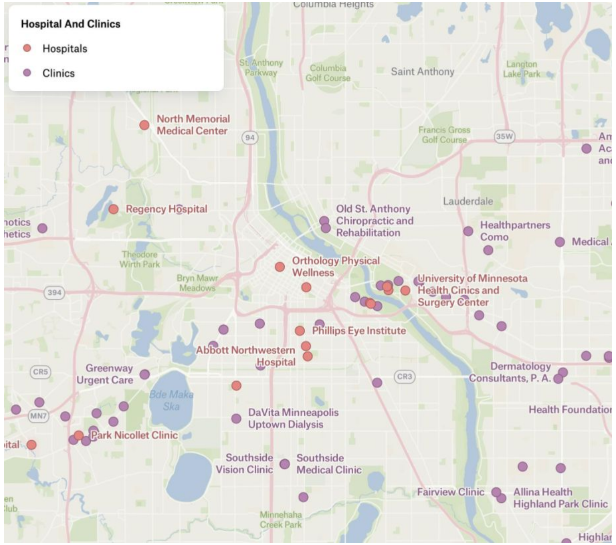
$$T^{(b)} = \mathrm{Var}\left(x_1^{(b)}, \ldots, x_n^{(b)}\right)$$

$$b = 1, \ldots, B$$

$$T_{obs} = \mathrm{Var}(x_1, \ldots, x_n)$$

$$p = \frac{\#\{T^{(b)} \geq T_{obs}\}+1}{B+1}$$

Permutation test



[Public facilities in Minneapolis]

Example of public resources: hospitals and clinics

Simple Example

	Community A	Community B	Community C	Community D
Pop	10000	20000	15000	5000
w	0.2	0.4	0.3	0.1
PR for accident	0.3	0.2	0.2	0.4
PR for congestion	0.2	0.2	0.1	0.2
PI	0.2	0.2	0.1	0.2
EPI	1	0.5	0.33	2
F	5	12	8	1
RA	0.0005	0.0006	0.0053	0.0002
Equity Indicator(x)	7.6	6.73	6.44	9.21

T_obs	1.17
Perms	999
Count T >= T_bos	29
p-value	0.03

⇩

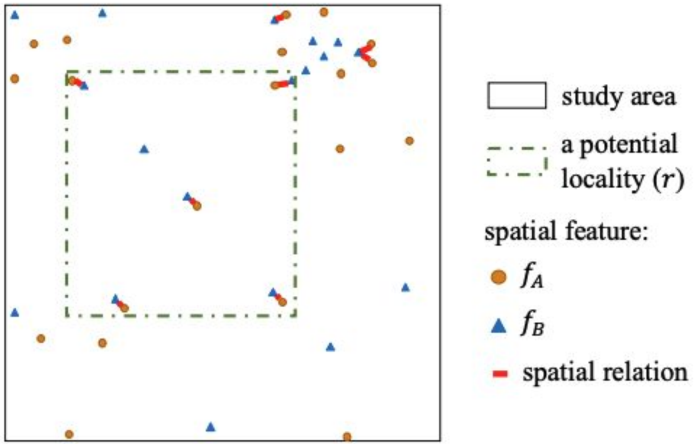
Spatial inequality of resources exists

Related Work：Spatial Co-location Pattern Mining

Spatial data mining research uses **co-location pattern discovery** to detect spatial features that frequently occur together.

Typical techniques include:

- **Data-unaware spatial partitioning**
  (e.g., QuadTree, grid-based partitioning)
- **Data-aware clustering methods**
  (detect localities based on clusters of spatial objects)



Yan Li, Shashi Shekhar (2018)

Application :

- Transportation / Traffic Analysis
- Urban Planning / Smart Cities

Related Work：Traffic Hotspot Detection

Previous studies analyze traffic crash patterns using **spatiotemporal clustering of crash records**.

The analysis also identified **three hotspot dynamics**:

- hotspot emergence
- hotspot stability
- hotspot disappearance

Table 1. Clustering results obtained using a three-year window for all traffic crashes which occurred on the Czech primary roads network between 2010 and 2018.

	10–12	11–13	12–14	13–15	14–16	15–17	16–18
No of hotspots	2242	2362	2369	2434	2482	2491	2561
Overall length [km]	266	274	283	296	303	307	323
Overall length [%]	6.8	7.0	7.2	7.5	7.7	7.8	8.2
No of TC within hotspots	7315	7775	8140	8719	9092	9417	9990
No of TC within hotspots [%]	47.7	47.9	47.3	47.2	47.3	45.6	46.5

Michal Bíl, Richard Andrášik, Jiří Sedoník (2019)

Limitations

Lack of integrated framework Existing research rarely integrates into a unified framework for traffic equity evaluation.

- spatial pattern mining
- temporal analysis
- demographic normalization
- public resource availability

Limitation In Spatial Equity Analysis

- Focuses on accessibility to infrastructure, rather than dynamic risk exposure such as traffic accidents.
- Doesn't incorporate spatiotemporal interactions between traffic events and community characteristics.

Experimental Methodology

Step1. Data Cleaning

Partitioning local area data to ensure consistent spatial units, taking traffic events, demographic data, and resource locations into the grid structure.

Step2. Detect Spatial-Temporal Co-location Patterns

Extract rush-hour traffic events, identify traffic features that frequently occur together during rush hours, computing Time-aware Participation Index.

Experimental Methodology

Step3. Equity Normalization

To account for population differences across communities, we compute population ratio and Equity-aware Participation Index (EPI).

$$EPI(C,r,t) = \frac{PI(C,t)}{w_r} \text{ where } w_r = \frac{Pop_r}{Pop_{total}}$$

*EPI, w are defined by ourselves
*Pop: population

Step4. Compare Communities

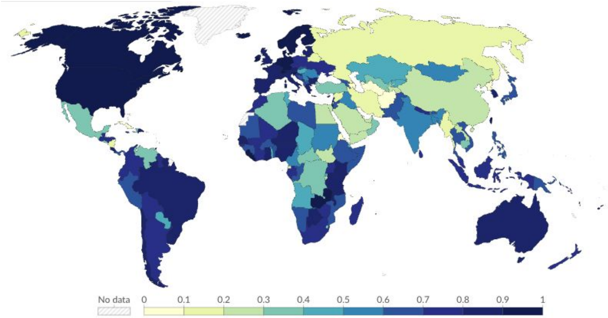
EPI values are compared across communities to identify areas with disproportionate traffic risk exposure.

Evaluation Metrics

The proposed framework will be evaluated using:

- Participation Index (PI)
- Equity-aware Participation Index (EPI)
- variance of normalized traffic risk
- p-values from permutation tests

These metrics measure both **spatial patterns and equity disparities**.



Example of Participation Index (PI):
Civil Society Participation Index, 2024

Darker colors represent higher event frequency.

Tasks and Interdependence

Spatial-Temporal Co-location Pattern Detection

extracting rush-hour traffic events, identifying co-occurring spatial features, computing **time Participation Index (PI)**

Output : Spatial-temporal traffic risk patterns.

Equity-aware Index Computation

Computing population ratio and Equity-aware Participation Index (**EPI**)

Output : Community-level traffic risk indicators.

Statistical Validation

Determine whether traffic risk distribution across communities is **statistically unequal**.

Weekly Plan

Week timeline	Tasks
03/16 - 03/20	data cleaning+initial code structure planning
03/23 - 03/27	Analyze rush-hour temporal patterns in the dataset
03/30 - 04/03	Define fairness metrics and complete the local co-location model
04/06 - 04/10	Model training
04/13 - 04/17	Analyze results and adjust the model
04/20 - 04/24	Final presentations begin

Question?

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