Dynamical efficiency in congested road network

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LUTS

MOTIVATION

This paper proposes a definition for describing and monitoring traffic condition in an **urban road network**. It was inspired by the classical efficiency in spatial network but with a **dependence on time**. Collecting data from various sources, like GPS signals, loop detectors, camera on the street, etc. has becoming always more often practice fact in traffic engineering and management. New and peculiar results and properties has been pointed out in this paper, in particular, by looking at the dynamical version of the efficiency and the change in betweenness centrality considering **evolving speed profile**.

BACKGROUND

CLASSICAL MEASURES IN URBAN ROAD NETWORKS

Different measures of centrality in spatial networks appear in the literature (see for example Crucitti et al, 2006):

$$C_i^S = \frac{1}{N-1} \sum_{j \in G, j \neq i} \frac{d_{ij}^{euc}}{d_{ij}}$$ *Straightness Centrality*

$$E = \frac{1}{N-1} \sum_{i \in G} \sum_{j \in G, j \neq i} \frac{d_{ij}^{euc}}{d_{ij}}$$ *Efficiency*

$$C_i^I = \frac{\Delta E}{E} = \frac{E(G) - E(G')}{E}$$ *Information centrality*

$$C_i^B = \frac{1}{(N-1)(N-2)} \sum_{j,k \in G, j \neq k \neq i} \frac{n_{jk}(i)}{n_{jk}}$$ *Betweenness Centrality*

⇒ All these measures come from the computation of **the all shortest path algorithm** among all pairs of nodes in a spatial network;

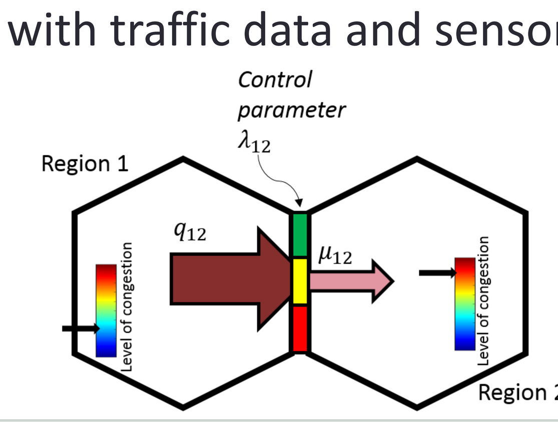
⇒ They **do not depend on time**;

⇒ *Information centrality* C_i^I compute the loss in efficiency in a network without link *l*, that is *percolation but not degradation*.

APPLICATIONS

APPLICATIONS IN TRAFFIC ENGINEERING

- Monitoring the traffic condition with a measure of potential efficiency and **connection easiness**;
- Classification of roads according to how convenient it **is in relation of its neighborhood** traffic condition;
- Thanks to its spatial smoothed values individualize **clusters** and connected congested components;
- Possibility to apply **dynamical perimeter control strategies**;
- Design better **usage of roads**, analyzing changes in betweenness centrality;
- D-Efficiency does **not need perfect and complete data** (often the case with traffic data and sensors)



METHODS

D-EFFICIENCY: CONGESTION PROPAGATION EFFECT

Thanks to speed data uploaded every 5 minutes we can compute the efficiency based on the ratio **between shortest time path and shortest path at maximum speed (in free flow condition).** In this way we compute the **local dynamical efficiency** (corresponding to the straightness centrality) and the **global dynamical efficiency** of the urban network $\mathcal{G}$. In formula:

$$DE(i,t) = \frac{1}{(N-1)} \sum_{\substack{j \neq i \\ j=1}}^{N} \frac{\tau_{i,j}^{ff}}{\tau_{i,j}(t)}$$

Local dynamical efficiency: How easy is to reach and/or to depart from node I from all the other nodes in the network

$$DE(\mathcal{G},t) = \frac{1}{N(N-1)} \sum_{i=1}^{N} \sum_{\substack{j \neq i \\ j=1}}^{N} \frac{\tau_{i,j}^{ff}}{\tau_{i,j}(t)}$$

Global dynamical efficiency: How the connectivity condition of the network $\mathcal{G}$ is due to congestion severity and distribution

☞ The D-Efficiency measures the **reachability** of each link, not as before in literature the average property of straightness;

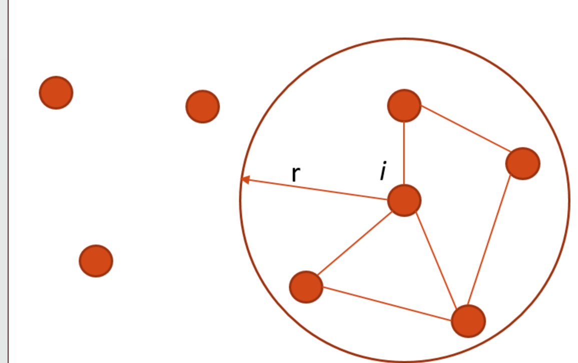
☞ It needs to run an **all shortest path algorithm** for each time step (in the application here $\Delta t = 5$ min);

☞ The average among all shortest paths allows to have also **incomplete link speed data** without losing the significance of the D-Efficiency.

HEURISTICS

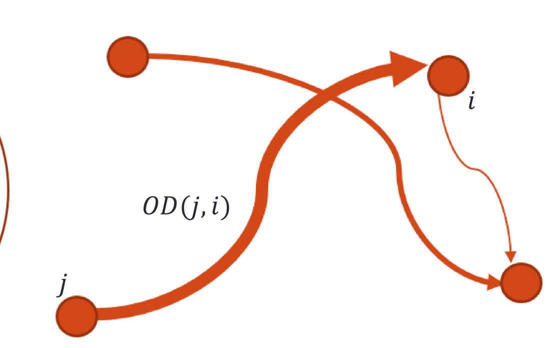
MAX-RADIUS AND OD-BASED APPROACH

In order to both reduce computational cost and measure the efficiency based on the users' usage, the following heuristics have been taken into account:



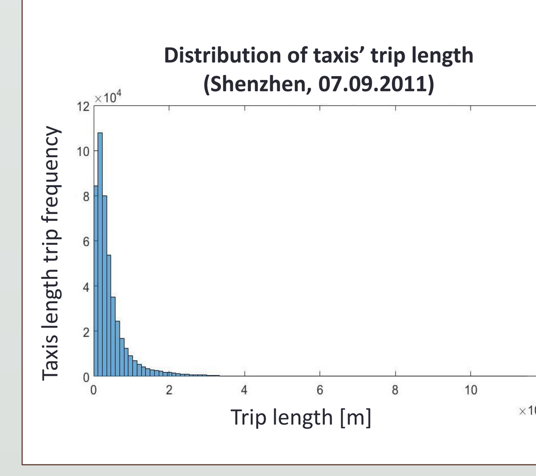
Shortest paths only between close nodes

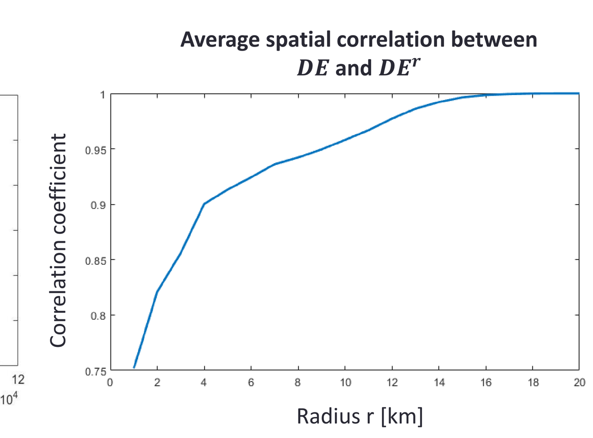
$$DE^r(i,t) = \frac{1}{(N-1)} \sum_{\substack{j \neq i \\ d(j,i) < r}} \frac{\tau_{i,j}^{ff}}{\tau_{i,j}(t)}$$



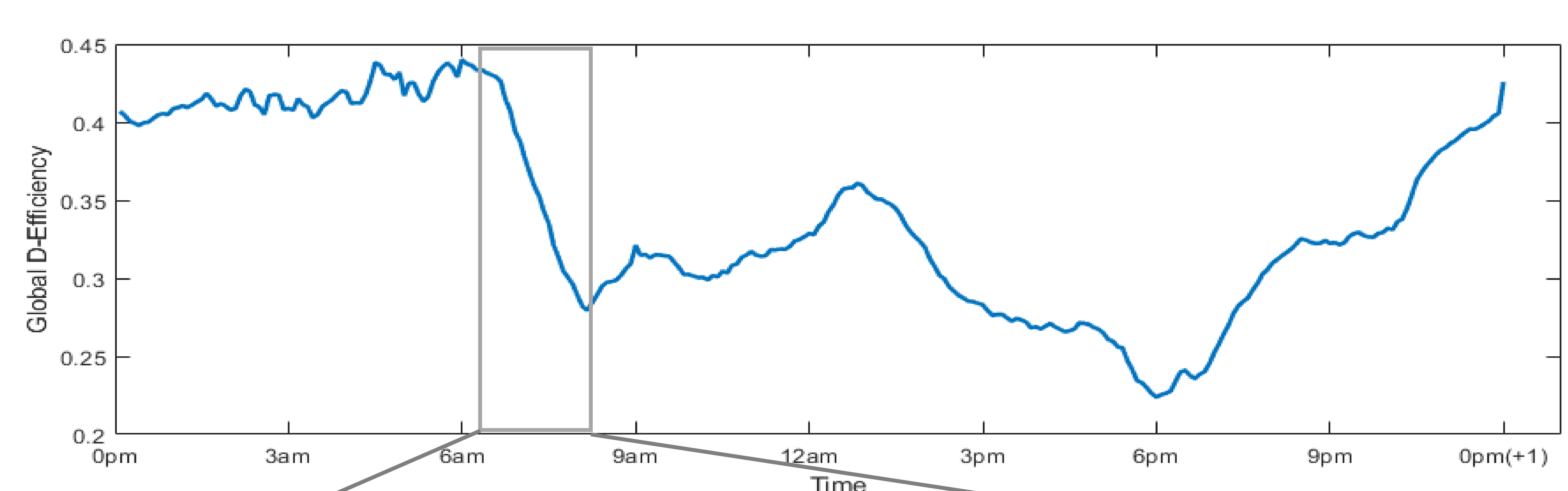
D-Efficiency weighted with OD information

$$DE^W(i,t) = \sum_{\substack{j \neq i \\ OD(j,i) > 0}} \frac{OD(j,i)}{\sum_{k \in N} OD(k,i)} \frac{\tau_{i,j}^{ff}}{\tau_{i,j}(t)}$$





RESULTS IN LARGE SCALE NETWORK



<u>Dataset</u>: GPS signals (with a frequency of 1 point every 30 secs) of more than 20k taxis spread in all the urban network

<u>How</u>: Map-Matching Algorithm to estimate average links' speeds every 5 mins

<u>Where</u>: Downtown Shenzhen, China

<u>When</u>: Tuesday 07.09.2011 (0-24h)